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# LIGHTWEIGHT DIESEL ENGINE DESIGNS FOR COMMUTER TYPE AIRCRAFT

(NASA-CR-165470) LIGHTWEIGHT DIESEL ENGINE  
DESIGNS FOR COMMUTER TYPE AIRCRAFT (Teledyne  
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Alex P. Brouwers  
Teledyne Continental Motors  
General Products Division  
76 Getty Street  
Muskegon, Michigan 49442

JULY 1981



PREPARED FOR:



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
LEWIS RESEARCH CENTER  
21000 BROOKPARK ROAD  
CLEVELAND, OHIO 44135  
CONTRACT NAS3-22149

**CONTRACTORS REPORT NO. 995  
NASA CR-165470**

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**TELEDYNE CONTINENTAL MOTORS  
General Products Division**

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## **1.0 SUMMARY**

This report describes the conceptual design and performance of two lightweight diesel engines for commuter type aircraft, capable of developing 1491 kW (2000 SHP) and 895 kW (1200 SHP) nominal propeller power at takeoff. The engines are flat rated to 4572 m (15000 ft.) altitude. The configurations and technologies that are applied are aimed at obtaining the best practical fuel consumption and the lightest power plant within the 1990's time frame specified. They are:

1. A radial cylinder configuration
2. Two-stroke cycle operation.
3. Insulated cylinders
4. Turbocompounding
5. High-pressure injection system
6. Advanced material technologies

The specific fuel consumption of the 1491 kW (2000 SHP) engine is projected at 182 g/kWh (.299 lb./HPh) at 4572 m (15000 ft.) cruise altitude. The weight of the engine is projected at 620 kg (1365 lb.) when advanced materials are applied resulting in a specific weight of .415 kg/kW (.683 lb./HP).

The specific fuel consumption of the 895 kW (1200 HP) engine is projected at 187 g/kWh (.308 lb./HPh) at 4572 m (15000 ft.) cruise altitude. The weight of this engine is projected at 465 kg (1025 lb.) when advanced materials are applied or .520 kg/kW (.854 lb/HP).

The study includes scaling information on the physical characteristics and engine performance over a power range from 670 kW (900 SHP) to 1865 kW (2500 SHP).

An advanced technology diesel engine with its very low SFC and light weight appears to be an attractive candidate for aircraft applications.

## **2.0 INTRODUCTION**

### **2.1 Purpose of the Study**

High propulsion system performance and fuel economy is essential for better airplane capabilities and enhanced usefulness of new airplane applications. Current commuter aircraft engines operate at reasonable levels of efficiency and reliability. However, the cost of fuel is becoming an increasingly larger factor in the operation of commercial aircraft.

The purpose of this study is to define conceptual designs and performance of advanced technology lightweight diesel engines which could be fuel-efficient alternative power plants to be used in studies of future commuter type aircraft.

Previous NASA funded studies of lightweight diesel engines for general aviation aircraft have shown that the diesel is a very fuel-efficient attractive alternate engine candidate. The diesel engine historically offers outstanding fuel economy and an ability to operate on a wide range of fuels. Advanced design and material technologies have the potential to substantially reduce weight and bulk and make the diesel engine a competitive power plant for commuter type aircraft.

### **2.2 Previous Large Aircraft Diesel Engines**

Although there have been many different aircraft diesel engines built, only two large engines were relatively successful and are listed because of their historical significance. Any new diesel engine proposed in this study with advanced technology would certainly have to show performance potential beyond these engines which are presented in Table I.

### **2.3 Scope of the Study**

The scope of the study is to perform a conceptual design, including performance and scaling investigation of two advanced technology aircraft engines of 1491 kW (2000 SHP) and 895 kW (1200 SHP) takeoff power for the 1990 time period. The study defines the configurations, technologies and physical characteristics of the engines and their performance in all flight regimes up to 7620m (25000 ft.) altitude. The engine performance requirement was a flat rating horsepower capability from sea level takeoff to 4572 m (15000 ft.)

### **2.4 Relative Merit of this Study to the General Field**

Although the study relates to commuter aircraft, the technologies described are as well applicable to other fields such as long range transports, helicopters, military vehicles and marine vessels where weight of the power plant and low fuel consumption are of extreme importance.

### **2.5 Significance of the Project**

The study has shown that the diesel engines have the potential for very low weights and significantly reduced fuel consumption when compared to current engines. Advanced technologies, such as adiabatic operation, turbocompounding and lightweight materials are used in this study.

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**TABLE I**  
**Previous Aircraft Diesels**

|                                  |                                   | <b>Junkers<br/>207 Turbo</b> | <b>Napier<br/>Nomad</b> |
|----------------------------------|-----------------------------------|------------------------------|-------------------------|
| <b>No. of Cylinders</b>          |                                   | <b>6</b>                     | <b>12</b>               |
| <b>Crankshaft<br/>T.O. Power</b> | <b>kW<br/>HP</b>                  | <b>746<br/>1000</b>          | <b>1984*<br/>2680</b>   |
| <b>Compounded<br/>T.O. Power</b> | <b>kW<br/>HP</b>                  |                              | <b>2274**<br/>3050</b>  |
| <b>Cooling</b>                   |                                   | <b>Liquid</b>                | <b>Liquid</b>           |
| <b>Cycle</b>                     |                                   | <b>2-Stroke</b>              | <b>2-Stroke</b>         |
| <b>Bore</b>                      | <b>mm<br/>in</b>                  | <b>120<br/>4.724</b>         | <b>152.4<br/>6.000</b>  |
| <b>Stroke</b>                    | <b>mm<br/>in</b>                  | <b>2 x 160<br/>2 x 6.299</b> | <b>187.3<br/>7.375</b>  |
| <b>Displ.</b>                    | <b>l<br/>in<sup>3</sup></b>       | <b>21.7<br/>1325</b>         | <b>41.0<br/>2502</b>    |
| <b>RPM</b>                       |                                   | <b>3000</b>                  | <b>2050</b>             |
| <b>BMEP</b>                      | <b>bar<br/>psi</b>                | <b>6.88<br/>100</b>          | <b>14.16<br/>205</b>    |
| <b>Piston Speed</b>              | <b>m/s<br/>fpm</b>                | <b>16.0<br/>3150</b>         | <b>12.8<br/>2520</b>    |
| <b>Spec. Power</b>               | <b>kW/l<br/>HP/in<sup>3</sup></b> | <b>34.4<br/>.75</b>          | <b>48.4*<br/>1.06</b>   |
| <b>Weight</b>                    | <b>kg<br/>lb</b>                  | <b>649<br/>1430</b>          | <b>1624<br/>3580</b>    |
| <b>Spec. Weight</b>              | <b>kg/kW<br/>lb/HP</b>            | <b>.87<br/>1.43</b>          | <b>.71**<br/>1.17</b>   |
| <b>BSFC</b>                      | <b>g/kWh<br/>lb/HPh</b>           | <b>219<br/>.360</b>          | <b>210**<br/>.345</b>   |

\*Piston Engine Power Only

\*\*Compounded

### **3.0 DESIGN STUDY OF THE 1491 kW (2000 SHP) ENGINE**

An initial preliminary study was conducted to determine the effect of current technologies and configuration on a diesel power plant.

#### **3.1 Preliminary Configuration Analysis Utilizing Modification of Past Aircraft Diesel Engine Data**

This analysis assumes that any power plant resulting from this study will be designed with improvements over the last generation aircraft diesel engines by utilizing current diesel technologies.

To obtain an initial approximation of the amount of improvement that may be possible by applying new technologies, the Napier Nomad aircraft diesel engine was used as a baseline upon which hypothesized new technologies were added. Although the ultimate configuration of the engine resulting from this study turned out to be quite different, the credibility of the analysis is supported by this initial hypothetical modified Nomad.

The simulation assumes that the cylinder cooling can be reduced by 30% based on today's advanced air-cooled engines.

The performance data of the original Nomad engine are:

|                      |                          |
|----------------------|--------------------------|
| Piston engine power  | 1983 kW (2660 HP)        |
| Excess turbine power | 291 kW (390 HP)          |
| SFC                  | 210 g/kWh (.345 lb/HP-h) |
| Fuel flow            | 478 kg/h (1052 lb/h)     |

Cooling test data of modern fully air-cooled diesel engines shows that cylinder cooling losses are approximately 13% of the energy input. Assuming a 30% reduction of these losses and 55% of the additional heat in the exhaust is recovered in the turbine, it follows that an additional 122kW (163 HP) turbine power would be available for turbocompounding by this reduction in cylinder cooling.

The performance data of this hypothetical Nomad engine then would have been:

|                      |                          |
|----------------------|--------------------------|
| Piston engine power  | 1983 kW (2660 HP)        |
| Excess turbine power | 413 kW (554 HP)          |
| SFC                  | 200 g/kWh (.328 lb/HP-h) |
| Fuel flow            | 478 kg/h (1052 lb/h)     |

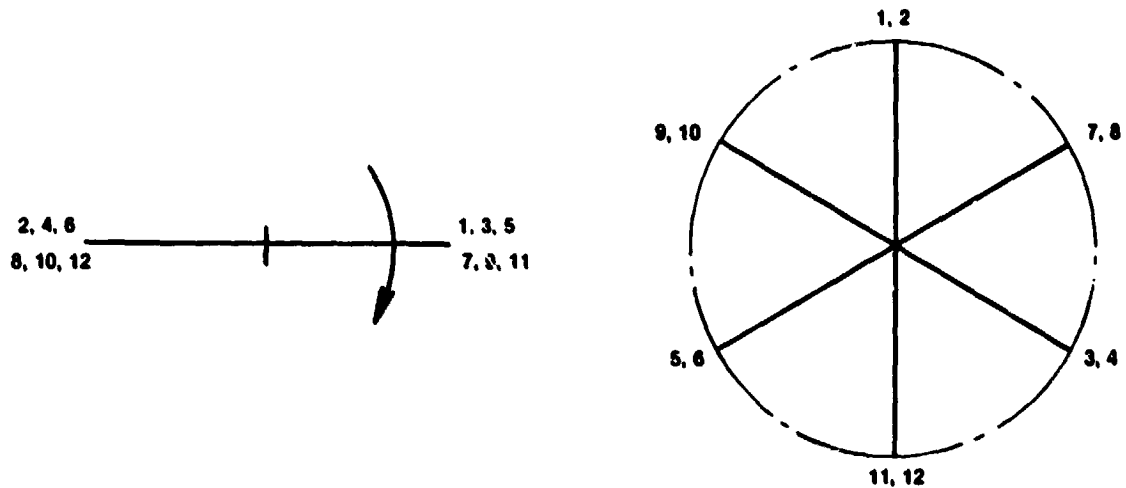
The piston engine portion of the overall turbocompound engine thus would contribute 83% of the total power.

Based on this value, initial approximations of the piston engine size could now be projected for a new engine at this hypothetical technology level, i.e. reduced cooling.

Disadvantages are:

- Requires a tunnel-crankcase
- Requires a barrel crankshaft (cheeks and main journal in one large disc). This type of shaft is heavy and can not be 100% balanced.

## 2. Opposed cylinders.



Firing order:

1, 12 — 9, 4 — 5, 8 — 11, 2 — 3, 10 — 7, 6 — 1, 12

Advantages are:

- Simple, vertically-split crankcase.
- Turbomachinery and accessories can be mounted above and below crankcase, thus offsetting the disadvantage of the longer crankcase on overall engine length.
- The crankshaft is easy to balance.
- There is no problem providing pendulum dampers.

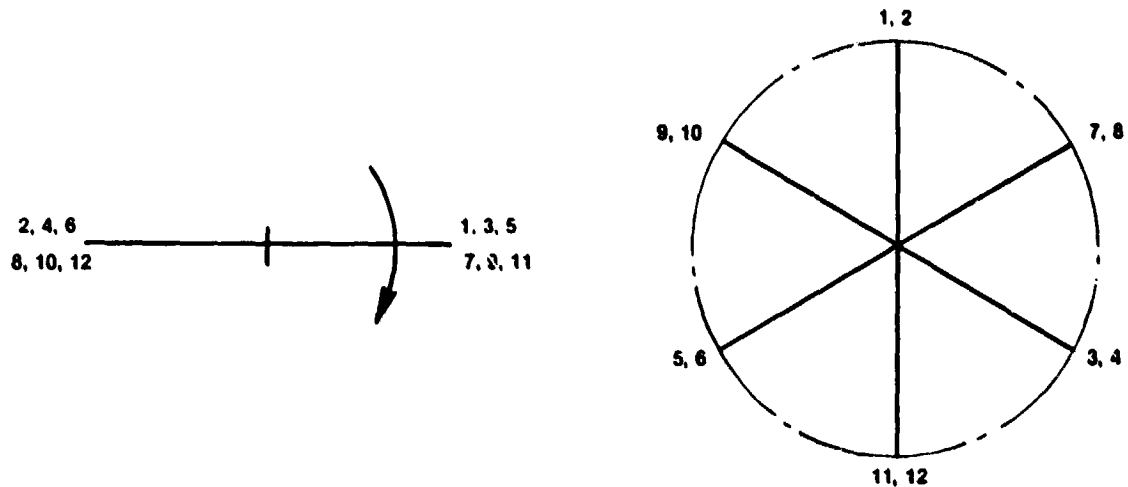
Disadvantages are:

- Increased engine weight due to longer crankcase and crankshaft.
- Two cylinders fire simultaneously, but always on opposite banks.
- Air-cooling will require more attention in the design phase than in the case of the radial engine.

Disadvantages are:

- Requires a tunnel-crankcase
- Requires a barrel crankshaft (cheeks and main journal in one large disc). This type of shaft is heavy and can not be 100% balanced.

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1, 12 — 9, 4 — 5, 8 — 11, 2 — 3, 10 — 7, 6 — 1, 12

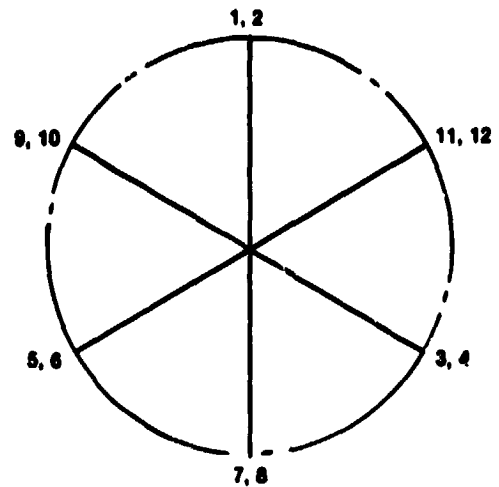
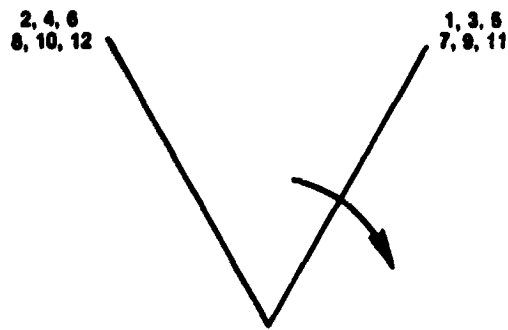
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- The crankshaft is easy to balance.
- There is no problem providing pendulum dampers.

Disadvantages are:

- Increased engine weight due to longer crankcase and crankshaft.
- Two cylinders fire simultaneously, but always on opposite banks.
- Air-cooling will require more attention in the design phase than in the case of the radial engine.

### 3. 60° V



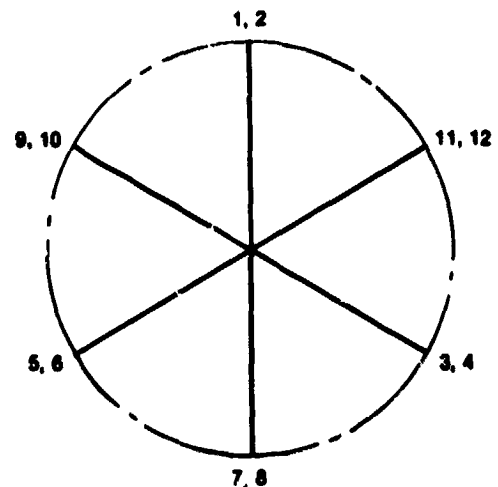
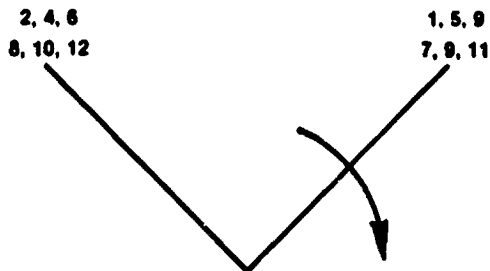
**Firing order:**

1, 10 — 9, 6 — 5, 8 — 7, 4 — 3, 12 — 11, 2 — 1, 10

**Disadvantages are:**

- Two cylinders fire simultaneously.
- Side loads on main bearing caps require a heavy crankcase structure.
- There is not much room inside the V for accessories.

### 4. 90° V



**Firing order:**

1 — 6 — 9 — 8 — 5 — 4 — 7 — 12 — 3 — 2 — 11 — 10 — 1

**Advantages are:**

- Regular 30° firing intervals.
- There is more room inside the V for accessories.

**Disadvantage:**

- Side loads on main bearing caps.

As a result of this initial evaluation opposed cylinders appear to be the best solution for a multi-cylinder configuration.

### **3.1.3 EVALUATION OF TECHNOLOGIES**

Based on the results of 3.1.2 a 12 cylinder engine with opposed cylinders was initially assumed and other relevant parameters were further evaluated. These included:

#### **1. Cooling**

##### **A. Air-cooling**

The advantages of air-cooling are:

- The cylinders can be individual: easy for maintenance and replacement.
- Air-cooling is more reliable:
  - No moving parts
  - No leaks

The disadvantages of air-cooling are:

- The cooling fins result in a larger cylinder spacing and thus a longer crankcase.
- More care needs to be taken to get adequate cooling of all cylinders.

##### **B. Liquid-cooling**

The advantages are:

- Equal cooling conditions of all cylinders.
- Shorter crankcase.

The disadvantages are:

- Less reliability.
- The bulk of a radiator is added to the engine.



**C. Effect of type of cooling on overall engine weight:**

A previous study of the 300 and 150 kW engines — NASA Report CR3260, — shows little difference in engine weights:

|               |             |
|---------------|-------------|
| Air-cooled    | 1.277 kg/kW |
| Liquid-cooled | 1.242 kg/kW |

A comparison is offered by two McCulloch aircraft engines:

TSIR-5190 Water-cooled, gasoline — excluding radiator and water pump  
201 kW, 179 kg (270 HP, 394 lb)  
Spec. weight .89 kg/kW (1.46 lb/HP)

TRAD-41d0 Air-cooled, diesel  
150 kW, 149 kg (201 HP, 329 lb)  
Spec. weight .99 kg/kW (1.63 lb/HP)

The higher specific weight of the diesel engine is due to higher firing pressures.

**D. Decision criteria**

The liquid cooled engine has the disadvantage of requiring a radiator and a water pump. This adds to the size of the power plant, reduces the reliability and requires more maintenance.

|                 | Air-cooled | Liquid-cooled |
|-----------------|------------|---------------|
| Reliability     | +          |               |
| Bulk            | +          |               |
| Weight          | Same       | Same          |
| Fuel economy    | Same       | Same          |
| Technology      | Same       | Same          |
| Maintainability | +          |               |
| Integration     | +          |               |
| Drag            | Same       | Same          |

Recommendation: Air-cooled design

**2. Cycle selection**

The two-stroke cycle system is selected for the same reasons outlined in the NASA reports CR3260 and CR3261.

Advantages:

- One power stroke per revolution.
- It results in a reduction of the engine weight due to the elimination of the valve trains, camshafts and camshaft drive.
- Engine reliability is improved.
- Engine frontal area is reduced, due to the elimination of the valves resulting in less frontal drag.

**Disadvantage:**

**Severe conditions are imposed on the turbocharger:**

- Compressor air flow is high because scavenge air must be delivered in addition to the combustion air.
- The turbine inlet temperature is reduced due to the mixing of the exhaust gas and the scavenge air.

This analysis of a turbocompounded, opposed 12 cylinder, air-cooled 2-stroke cycle configuration indicates that such an engine will be large and heavy. The predicted compounded BSFC of 200 g/kWh (.328 lb./HPH) is good but much higher than can be expected for a compounded power plant with insulated cylinders. (BSFC's less than 182 g/kWh — .300 lb./HPH — have been obtained with the CUMMINS adiabatic engine.) It was, therefore, concluded that an engine which utilizes state-of-the-art technologies will not be competitive with current commuter power plants. As a result of this initial analysis the modified Nomad configuration was discarded.

**Advanced technologies must be applied:**

1. High BMEP's
2. High piston speeds
3. Insulated cylinders (reduced cooling)
4. High-pressure fuel injection.
5. Lightweight materials and components
6. High performance turbine and compressor.

### **3.2 Configuration and Technology Analysis of an Advanced 1491 kW (2000 SHP) Engine**

An all new engine concept based on technology developed in other NASA studies (Ref. 1 and 2) was assumed. After several iterations and trade-offs the resultant configuration schematic is shown in Figure 3-1.

#### **3.2.1 ENGINE FEATURES**

The configuration and technologies applied to the commuter type engine to obtain practical low fuel consumption and light weight are:

1. A radial cylinder configuration.

Prior NASA funded studies of diesel engines for general aviation aircraft (NASA reports CR3260 and CR3261) have shown that this configuration results in the lightest possible power plant for a given engine power. These studies also showed that the radial configuration does not result in an excessively large frontal area of the engine.

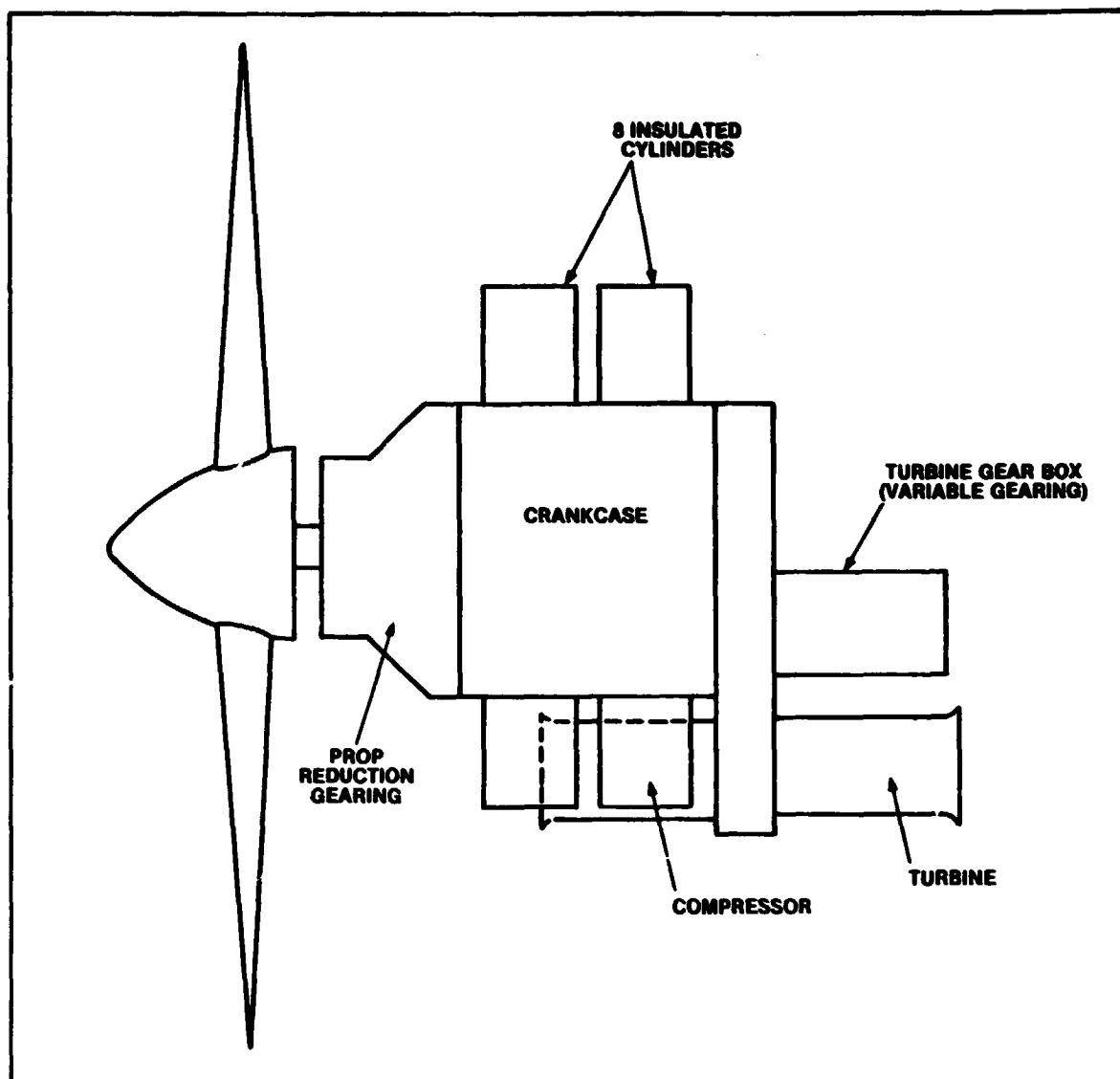


FIGURE 3-1 — SCHEMATIC OF THE 1491 kW 2-STROKE CYCLE ENGINE

## 2. Insulated cylinders.

As discussed in paragraph 3.1 significant gains are available by using insulated cylinders. With insulated cylinders the diverted cooling energy results in an increase of the enthalpy of the exhaust gases and is partially recovered in the turbine.

## 3. Turbocompounding.

The excess power from the turbine is fed back into the propeller gear train. More useful power can thus be obtained from the same amount of fuel. This results in very low SFC's of the power plant.

#### **4. High-pressure injection system.**

One of the most critical technologies of the proposed engines is the fuel system. The primary prerequisite for optimum combustion efficiency is a thorough mixing of fuel and air. In a four-stroke cycle engine this is in part accomplished by the swirling motion of the air in the cylinder. Optimum scavenging of the cylinder of a loop-scavenged two-stroke cycle engine, however, dictates the absence of induced turbulence. The mixing of fuel and air must thus be obtained by maximum penetration and atomization of the fuel. This requires high injection pressures.

Additionally, the thorough mixing of air and fuel combined with the high temperatures of insulated cylinders, make the engines less sensitive to the type and quality of the fuel.

#### **5. Advanced material technologies.**

The use of composites and high-strength materials will result in appreciable weight reductions.

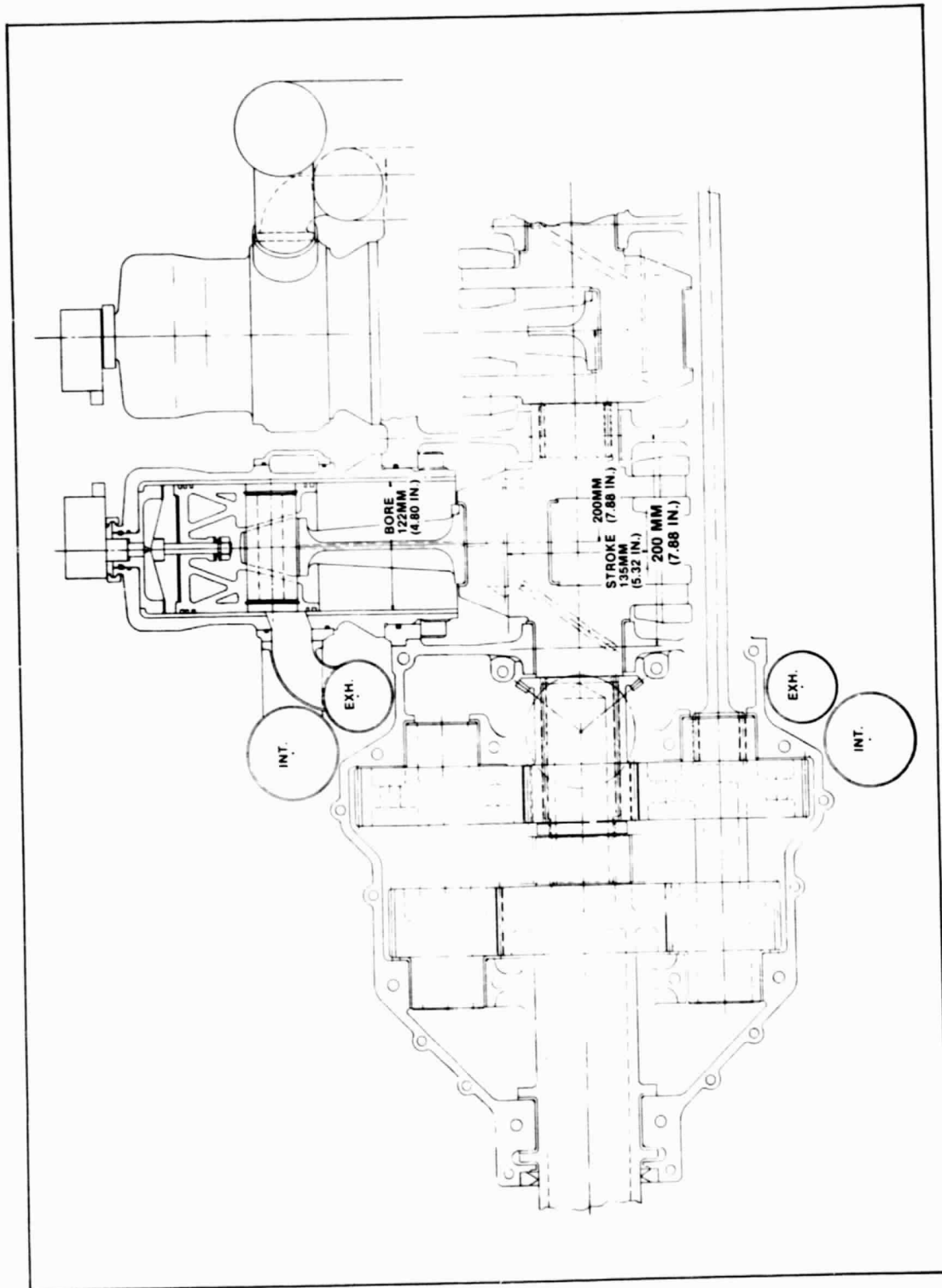


FIGURE 3-2 — 1491 kW COMMUTER AIRCRAFT DIESEL PARTIAL LONGITUDINAL SECTION

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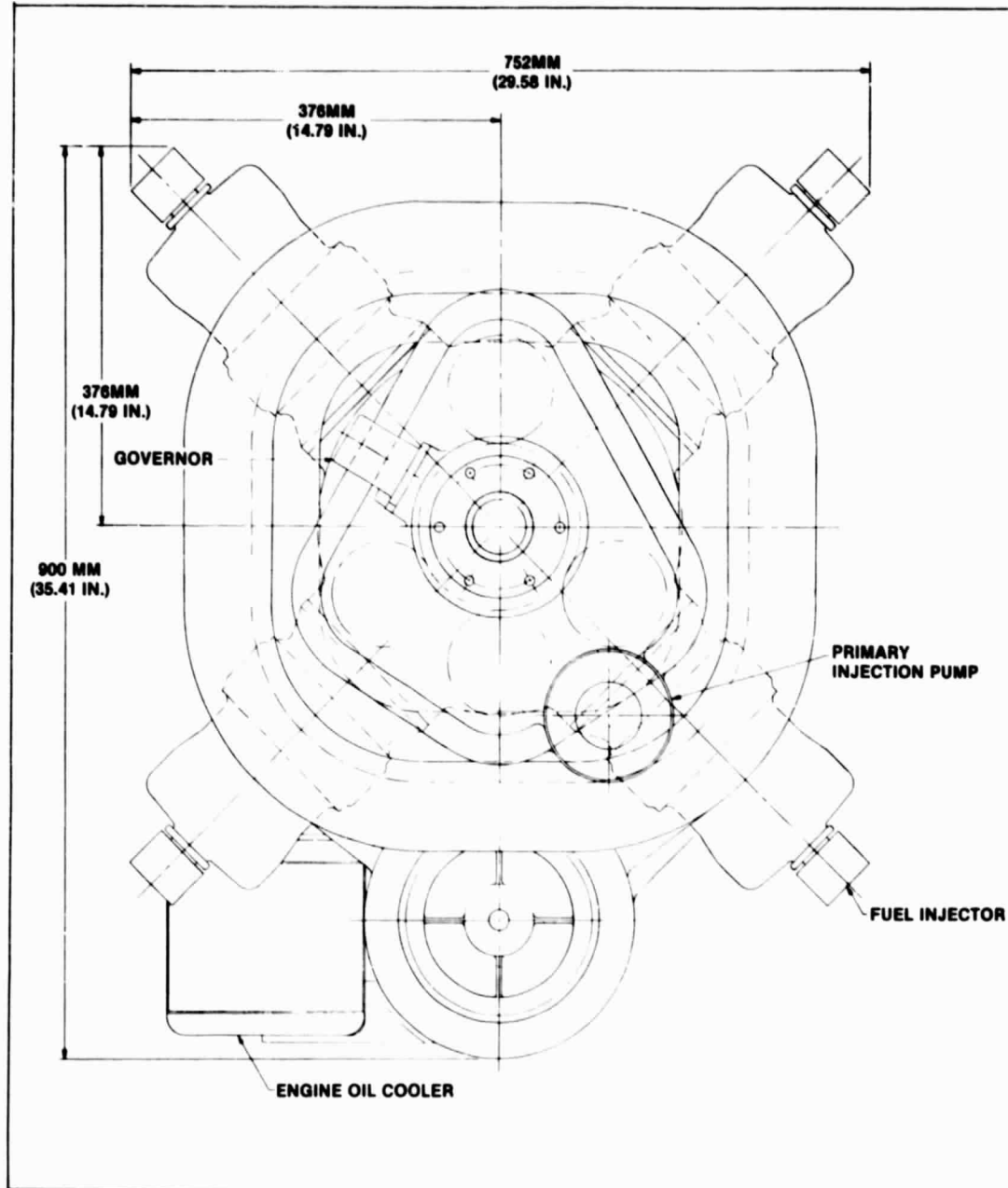


FIGURE 3-3 — 1491 kW COMMUTER AIRCRAFT DIESEL — FRONT VIEW

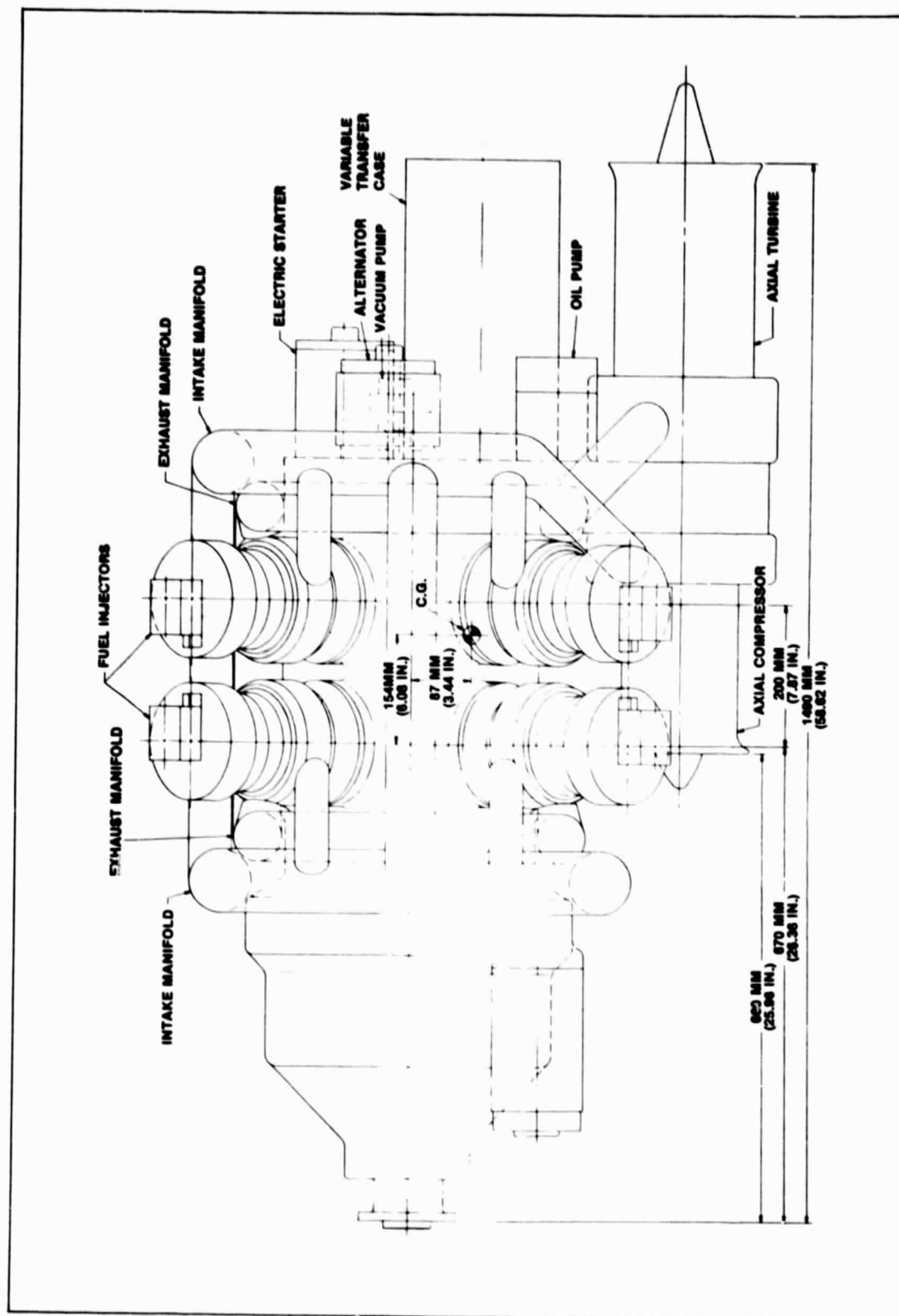


FIGURE 3-4 — 1431 kW COMMUTER AIRCRAFT DIESEL — SIDE VIEW

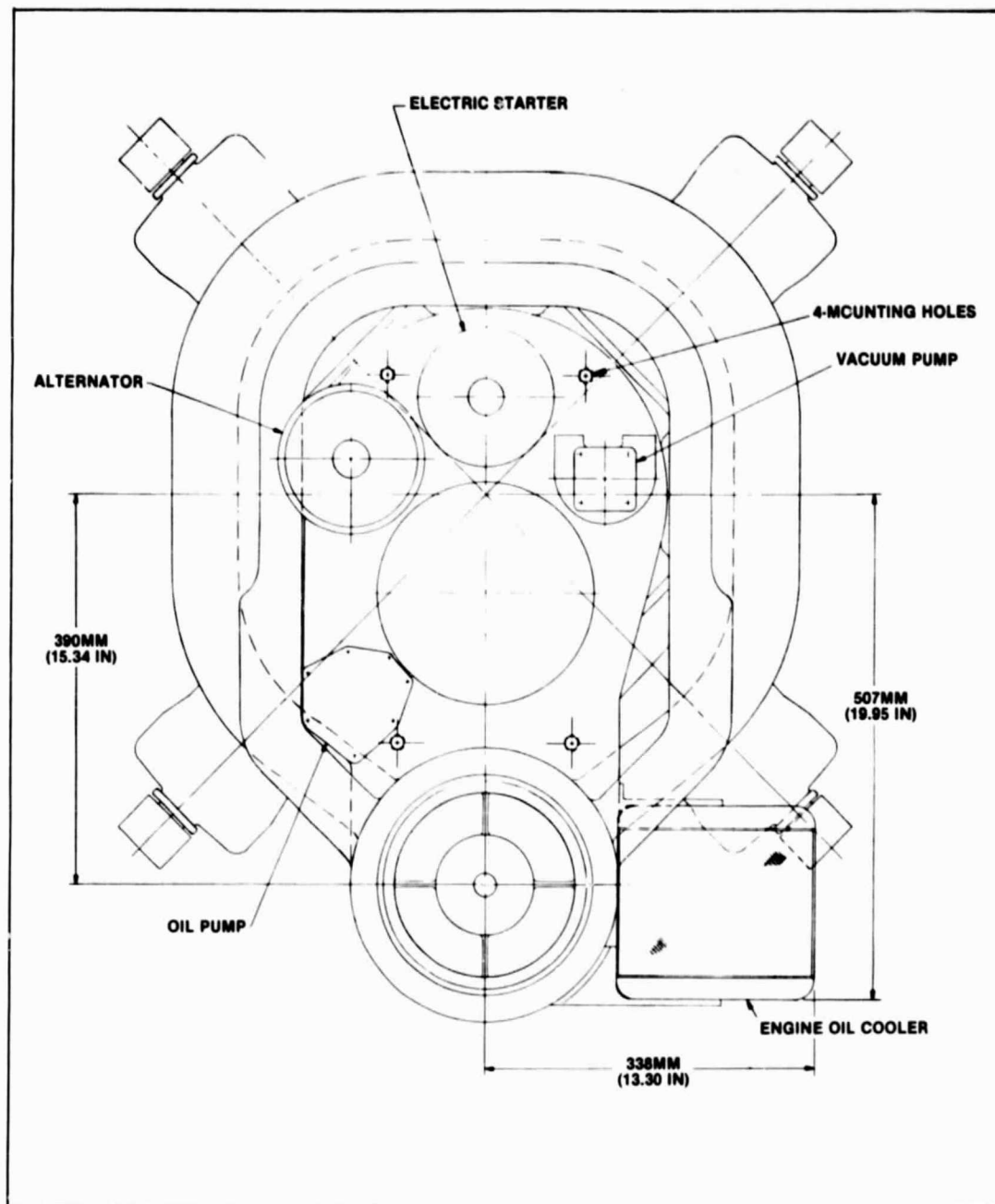


FIGURE 3-5 — 1491 kW COMMUTER AIRCRAFT DIESEL — REAR VIEW



### 3.2.2 ENGINE CONCEPT DESIGN

Three views and a partial section of the engine are shown in the Figures 3-2 through 3-5.

The eight cylinder arrangement which was finally chosen is a compromise between frontal area and weight of the engine.

The experience gained in the design of the general aviation diesel engines (NASA report CR3261, page 9) indicates that the lightest possible radial engine is obtained when the lowest number of cylinders is chosen for a given engine displacement.

The cylinders are arranged in two rows of four cylinders each. Locating the cylinders at a 45° angle allows placement of the compressor between the bottom cylinders. The Schnuerle type loop scavenging system is chosen because it is known to require the least amount of scavenge air, which in turn reduces the required compressor power, Figure 3-6.

The cylinder liners and the tops of the pistons utilize insulating materials in order to retain as much heat in the exhaust gases as possible.

The propeller reduction gearing consists of driving and driven sun gears and three sets of compound pinions.

No manifolds are located between the two rows of cylinders in order to keep the crankcase as short and stiff as possible.

The compressor and the turbine are both of the axial type. The axial staging is chosen for the following reasons:

1. Axial units have less bulk and weigh less than radial ones, in particular for high mass flows.
2. The high compressor pressure ratio (8:1) required for cruising can be obtained more easily with an axial unit than with a centrifugal compressor.
3. The overall diameter of the compressor housing is small and allows for a very favorable packaging location between any of the cylinders. The design shown arbitrarily has the turbocompressor located on the bottom of the engine.

The turbine is connected to the crankshaft by means of an infinitely variable speed reducing device. This allows a high compressor speed at starting and low engine speeds and prevents overspeeding at high engine speeds.

Conventional starter and alternator units are located at the rear of the engine. A separate turbocharger-mounted alternator for independent electrical power and air starting was initially considered. This scheme would be similar to that proposed in CR3261 for the 186 kW engine (Figure 3-7). Although this is a desirable feature, it required a complete weight and performance trade-off study between the alternatives which was beyond the scope of this study. When such a trade-off study is made consideration should be given to utilize a separate auxiliary power unit to supply electrical power independent of the main engine. This APU could then also be a source of hot compressed air for preheating of the engine on cold days and provide air for a bleed air starter.

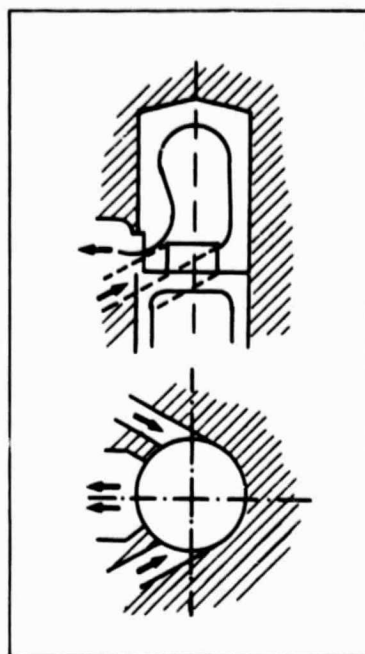


FIGURE 3-6 — SCHNUERLE TYPE LOOP SCAVENGING

### 3.2.3 ENGINE OPERATING DATA

Engine operating parameters were determined for 5 flight conditions:

1. Max. power at takeoff
2. Max. power at 4570 m (15000 ft.)
3. Max. power at 7620 m (25000 ft.)
4. 65% power at 4570 m (15000 ft.)
5. 65% power at 7620 m (25000 ft.)

### 3.2.4 PROJECTION OF FUEL CONSUMPTION AND AVAILABLE TURBINE POWER

in order to conduct the cycle analysis calculations it is necessary to first establish the piston engine characteristics and the expected BSFC. To define these parameters a second simulation was made of the Napier Nomad engine performance using very advanced technologies including adiabatic operation. The numbers used are based on published test data (Reference 3).

#### 1. Published performance data (Water-cooled):

|                          |                |                  |
|--------------------------|----------------|------------------|
| Piston engine max. power | 1983 kW        | (2660 HP)        |
| Excess turbine power     | 291 kW         | (390 HP)         |
| Compounded power         | 2274 kW        | (3050 HP)        |
| Compounded SFC           | 210 g/kWh      | (.345 lb/HPh)    |
| Fuel flow                | 477 kg/h       | (1052 lb/h)      |
| Piston engine BSFC       | 240 g/kWh      | (.395 lb/HPh)    |
| Energy input             | 81520 kcal/min | (323490 BTU/min) |

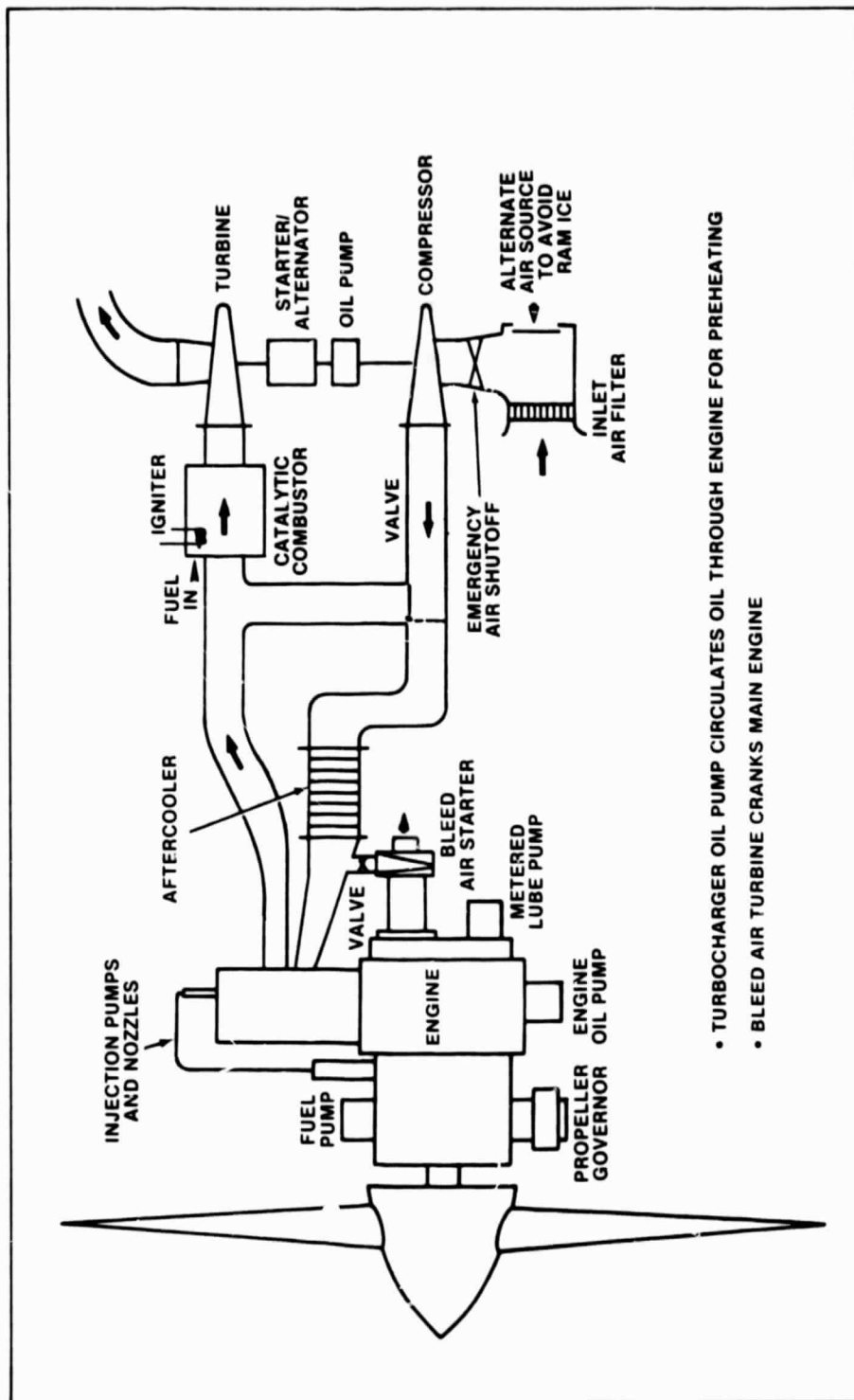


FIGURE 3-7 — SCHEMATIC 2-STROKE ENGINE WITH INDEPENDENT TURBO LOOP

## 2. Simulated performance with insulated cylinders:

Cylinder cooling requires approximately 13% of the energy input (TCM/GPD experience). Recovery of this energy in the turbine is approximately 55% or 406 kW (545 HP).

The excess turbine power becomes:

$$\begin{aligned} 291 + 406 &= 697 \text{ kW} \\ (390 + 545 &= 935 \text{ HP}) \end{aligned}$$

The compounded power becomes:

$$\begin{aligned} 1983 + 697 &= 2680 \text{ kW} \\ (2660 + 935 &= 3595 \text{ HP}) \end{aligned}$$

## 3. Further modification of this design by the use of radial cylinder configuration and reduced friction:

The mechanical efficiency of the original Nomad engine as published was 86%. This was assumed to improve to 90% due to a reduction of the number of cylinders and main bearings. Therefore,

|                        |         |           |
|------------------------|---------|-----------|
| Corrected engine power | 2075 kW | (2783 HP) |
| Excess turbine power   | 697 kW  | (935 HP)  |
| Compounded power       | 2772 kW | (3718 HP) |

## 4. Effect of very high injection pressures and electronic timing control:

High injection pressures result in improved atomization and better penetration and mixing with the air in the cylinder. A 5% improvement of the fuel consumption is expected from the improved combustion efficiency.

|                     |          |             |
|---------------------|----------|-------------|
| Corrected fuel flow | 454 kg/h | (1000 lb/h) |
|---------------------|----------|-------------|

## 5. The maximum cruise power performance of such a hypothetical Nomad engine thus would be:

|                      |           |               |
|----------------------|-----------|---------------|
| Piston engine power  | 2075 kW   | (2783 HP)     |
| Excess turbine power | 697 kW    | (935 HP)      |
| Compounded power     | 2772 kW   | (3718 HP)     |
| Fuel flow            | 454 kg/h  | (1000 lb/h)   |
| Piston engine BSFC   | 219 g/kWh | (.359 lb/HPh) |
| Compounded SFC       | 164 g/kWh | (.267 lb/HPh) |

The turbine excess power thus would be 25% of the compounded power.

### 3.2.5 ENGINE CHARACTERISTICS AND CYCLE ANALYSIS DATA

In order to start the cycle calculations it is necessary to estimate the power of the piston engine. Using the analysis in Section 3.2.4 the engine power was chosen at 1118 kW (1500 HP). After several iterations of the cycle calculations the engine power was found to be 1342 kW (1803 HP). The end result of the calculations is shown in Table II. The average percentage of the excess turbine power is 21% which is reasonably close to the estimated 25% derived in Section 3.2.4.

**TABLE II**  
**1491 kW Operating Parameters**

| Altitude                | m<br>ft | Takeoff       | 100% Power    |               | 65% Power     |               |
|-------------------------|---------|---------------|---------------|---------------|---------------|---------------|
|                         |         | Sea Level     | 4572<br>15000 | 7620<br>25000 | 4572<br>15000 | 7620<br>25000 |
| 1. PISTON ENGINE        |         |               |               |               |               |               |
| Engine Power            | kW      | 1342          | 1257          | 887           | 839           | 623           |
|                         | HP      | 1803          | 1685          | 1190          | 1125          | 835           |
| Engine Speed            | RPM     | 4000          | 4000          | 4000          | 3000          | 3000          |
| Bore x Stroke           | mm      | 122 x 135     |               |               |               |               |
|                         | in.     | 4.803 x 5.336 |               |               |               |               |
| Piston Speed            | m/s     | 18.0          | 18.0          | 18.0          | 13.5          | 13.5          |
|                         | fpm     | 3557          | 3557          | 3557          | 2668          | 2668          |
| Number of Cylinders     |         | 8             |               |               |               |               |
| Displacement            | ℓ       | 12.673        |               |               |               |               |
|                         | cu. in  | 773.36        |               |               |               |               |
| BMEP                    | bar     | 15.89         | 14.87         | 10.50         | 13.24         | 9.83          |
|                         | psi     | 230.4         | 215.7         | 152.3         | 192.0         | 142.5         |
| Engine BSFC             | g/kWh   | 228.1         | 215.9         | 215.9         | 209.8         | 209.8         |
|                         | lb/HPh  | .375          | .355          | .355          | .345          | .345          |
| Fuel Flow               | kg/h    | 306           | 271           | 191           | 176           | 131           |
|                         | lb/h    | 675           | 598           | 422           | 388           | 288           |
| Ambient Press           | bar     | 1.014         | .572          | .376          | .572          | .376          |
|                         | psi     | 14.71         | 8.30          | 5.46          | 8.30          | 5.46          |
| Ambient Temp            | °C      | 15.9          | − 14.5        | − 34.3        | − 14.5        | − 34.3        |
|                         | °F      | 60.0          | 5.3           | − 30.4        | 5.3           | − 30.4        |
| Estimated Airspeed      | kmh     |               | 696           | 691           | 561           | 568           |
|                         | knots   |               | 376           | 373           | 303           | 307           |
|                         | Mach    |               | .60           | .62           | .48           | .51           |
| Stagn. Press            | bar     |               | .730          | .488          | .670          | .447          |
|                         | psi     |               | 10.59         | 7.08          | 9.71          | 6.48          |
| Stagn. Temp.            | °C      |               | 4.2           | − 16.0        | − 2.6         | − 22.4        |
|                         | °F      |               | 39.0          | 2.6           | 26.7          | − 9.0         |
| Compressor Press. Ratio |         | 6.0:1         | 8.0:1         | 8.0:1         | 6.5:1         | 6.5:1         |
| Int. Man. Press         | bar     | 6.02          | 5.76          | 3.85          | 4.31          | 2.86          |
|                         | psi     | 87.36         | 83.52         | 55.80         | 62.47         | 41.44         |
| Int. Man. Temp          | °C      | 245           | 263           | 235           | 224           | 188           |
|                         | °F      | 472           | 504           | 454           | 435           | 370           |

**TABLE II (Continued)**  
**1491 kW Operating Parameters**

| Altitude  | m<br>ft      | Takeoff       | 100% Power    |                | 65% Power     |               |
|---|--------------|---------------|---------------|----------------|---------------|---------------|
|   |              | Sea Level     | 4572<br>15000 | 7620<br>25000  | 4572<br>15000 | 7620<br>25000 |
| Ratio $\frac{\text{Int. Man. Press.}}{\text{Exh. Man. Press.}}$ |              | 1.250         | 1.250         | 1.250          | 1.115         | 1.115         |
| Exh. Man. Press   | bar<br>psi   | 4.82<br>69.89 | 4.61<br>66.82 | 3.08<br>44.64  | 3.86<br>56.02 | 2.56<br>37.17 |
| Scavenge System Schnuerle Loop Scavenging                       |              |               |               |                |               |               |
| Height Int. Ports   | mm<br>in     |               |               | 39<br>1.535    |               |               |
| Height Exh. Ports   | mm<br>in     |               |               | 28<br>1.102    |               |               |
| Effective Compr. Ratio  |              |               |               | 9:1            |               |               |
| Nominal Compr. Ratio  |              |               |               | 12.25:1        |               |               |
| Nominal Piston Displ.   | ℓ<br>cu. in  |               |               | 1.841<br>96.67 |               |               |
| Eff. Piston Displ.  | ℓ<br>cu. in  |               |               | 1.126<br>68.74 |               |               |
| Scavenge Ratio  | *            |               |               | 1              |               |               |
| Scavenge Efficiency   | **           |               |               | .725           |               |               |
| Charging Efficiency   | ***          |               |               | .58            |               |               |
| Fuel Flow   | kg/h<br>lb/h | 306<br>675    | 271<br>598    | 191<br>422     | 176<br>388    | 131<br>288    |
| Compressor Air Flow   | kg/s<br>lb/s | 3.41<br>7.52  | 3.15<br>6.95  | 2.22<br>4.89   | 1.94<br>4.28  | 1.38<br>3.04  |
| Trapped Air Flow  | kg/s<br>lb/s | 1.98<br>4.36  | 1.83<br>4.03  | 1.29<br>2.84   | 1.12<br>2.48  | .80<br>1.76   |
| Scavenge Air Flow   | kg/s<br>lb/s | 1.43<br>3.16  | 1.32<br>2.92  | .93<br>2.05    | .82<br>1.80   | .58<br>1.28   |
| Air/Fuel Ratio-Trapped  |              | 23.4          | 24.4          | 24.0           | 23.0          | 22.0          |
| Air/Fuel Ratio-Delivered  |              | 40.3          | 41.8          | 41.7           | 39.6          | 38.1          |

$$* \text{Scavenge Ratio } R_s = \frac{W_{\text{air delivered}}}{V_{\text{displ}} \cdot d_1}$$

$$** \text{Scavenge Efficiency } \eta_{sc} = \frac{V_{\text{trapped}}}{V_1}$$

$$*** \text{Charging Efficiency } \eta_{ch} = \frac{W_{\text{trapped}}}{V_{\text{displ}} \cdot d_1}$$

**TABLE II (Continued)**  
**1491 kW Operating Parameters**

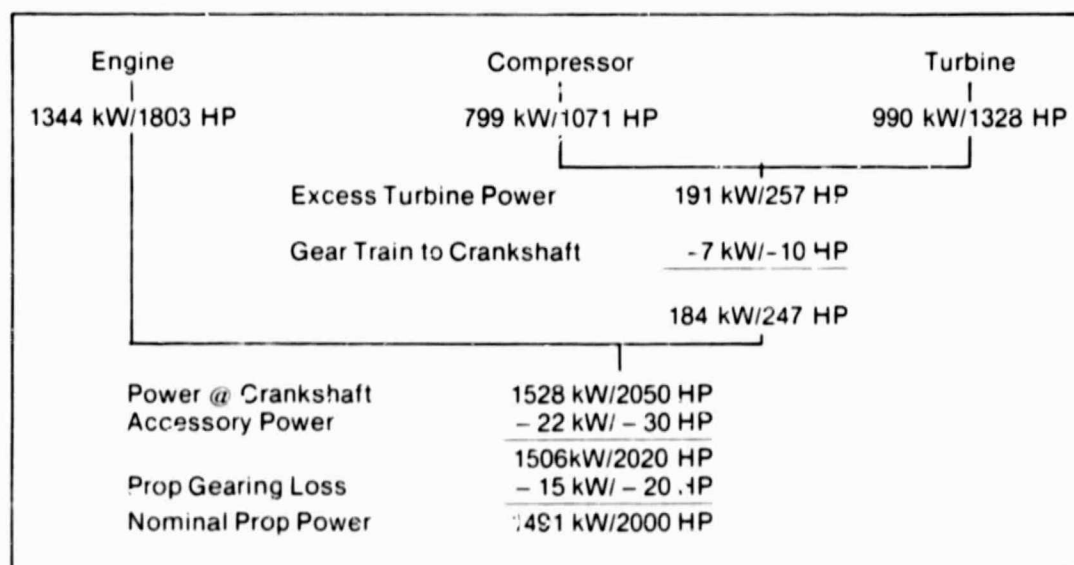
| Altitude                     | m<br>ft | Takeoff   | 100% Power    |               | 65% Power     |               |
|------------------------------|---------|-----------|---------------|---------------|---------------|---------------|
|                              |         | Sea Level | 4572<br>15000 | 7620<br>25000 | 4572<br>15000 | 7620<br>25000 |
| Peak Firing Pressure         | bar     | 164.8     | 156.3         | 105.0         | 118.9         | 79.9          |
|                              | psi     | 2390      | 2267          | 1523          | 1725          | 1159          |
| Peak Combustion Temp         | °C      | 2244      | 2241          | 2181          | 2179          | 2135          |
|                              | °F      | 4070      | 4066          | 3958          | 3953          | 3874          |
| <b>2. COMPRESSOR/TURBINE</b> |         |           |               |               |               |               |
| Compressor Air Flow          | kg/s    | 3.41      | 3.15          | 2.22          | 1.94          | 1.38          |
|                              | lb/s    | 7.52      | 6.95          | 4.89          | 4.28          | 3.04          |
| Press. Ratio Compressor      |         | 6.0:1     | 8.0:1         | 8.0:1         | 6.5:1         | 6.5:1         |
| Adiab. Compr. Eff.           |         | .87       | .86           | .86           | .87           | .87           |
| Polytr. Compr. Eff.          |         | .90       | .89           | .89           | .90           | .90           |
| Compr. Discharge Temp.       | °C      | 245       | 263           | 235           | 224           | 188           |
|                              | °F      | 472       | 504           | 454           | 435           | 370           |
| Compressor Power             | kW      | 792       | 825           | 564           | 445           | 295           |
|                              | HP      | 1061      | 1106          | 756           | 597           | 395           |
| Bearing Loss                 | kW      | 7         | 7             | 6             | 4             | 3             |
|                              | HP      | 10        | 10            | 8             | 6             | 4             |
| Compr. + Bearings            | kW      | 799       | 832           | 570           | 450           | 298           |
|                              | HP      | 1071      | 1116          | 764           | 603           | 399           |
| Turbine Gas Flow             | kg/s    | 3.50      | 3.23          | 2.27          | 1.99          | 1.42          |
|                              | lb/s    | 7.71      | 7.12          | 5.01          | 4.38          | 3.12          |
| Turbine Inlet Temp           | °C      | 595       | 603           | 575           | 581           | 553           |
|                              | °F      | 1103      | 1117          | 1067          | 1077          | 1026          |
| Press. Ratio Turbine         |         | 4.73:1    | 8.00:1        | 8.10:1        | 6.72:1        | 6.76:1        |
| Adiab. Turbine Eff.          |         | .89       | .88           | .88           | .89           | .89           |
| Turbine Power                | kW      | 990       | 1146          | 785           | 651           | 450           |
|                              | HP      | 1328      | 1537          | 1053          | 873           | 603           |
| Excess Turbine Power         | kW      | 191       | 314           | 215           | 201           | 152           |
|                              | HP      | 257       | 421           | 289           | 270           | 204           |
| Net Prop. Power              | kW      | 1491      | 1491          | 1033          | 969           | 708           |
|                              | HP      | 2000      | 2000          | 1385          | 1300          | 950           |
| Fuel Flow                    | kg/h    | 305       | 271           | 191           | 176           | 131           |
|                              | lb/h    | 675       | 598           | 422           | 388           | 288           |

**TABLE II (Continued)**  
**1491 kW Operating Parameters**

| Altitude             | m<br>ft        | Takeoff   | 100% Power    |               | 65% Power     |               |
|----------------------|----------------|-----------|---------------|---------------|---------------|---------------|
|                      |                | Sea Level | 4572<br>15000 | 7620<br>25000 | 4572<br>15000 | 7620<br>25000 |
| Compound SFC         | g/kWh          | 205       | 182           | 185           | 182           | 185           |
| with Accessory Power | lb/HPh         | .338      | .298          | .303          | .298          | .303          |
| Excess Turbine Power | $\times 100\%$ | 12.8      | 21.1          | 20.8          | 20.7          | 21.5          |
| Net Prop. Power      |                |           |               |               |               |               |
| Compound Power       | kW             | 1513      | 1547          | 1089          | 1025          | 764           |
| W/O Accessory Power  | HP             | 2030      | 2075          | 1460          | 1375          | 1025          |
| SFC W/O Accessory    | g/kWh          | 202       | 175           | 175           | 172           | 171           |
| Power                | ****lb/HPh     | .332      | .288          | .289          | .282          | .281          |

\*\*\*\*The SFC without accessory power is a true representation of the fuel economy of the basic power plant.

The Figures 3-8 through 3-12 show the compounded power schematics for the five flight conditions calculated above.



**FIGURE 3-8 — POWER SCHEMATIC TAKEOFF MODE**



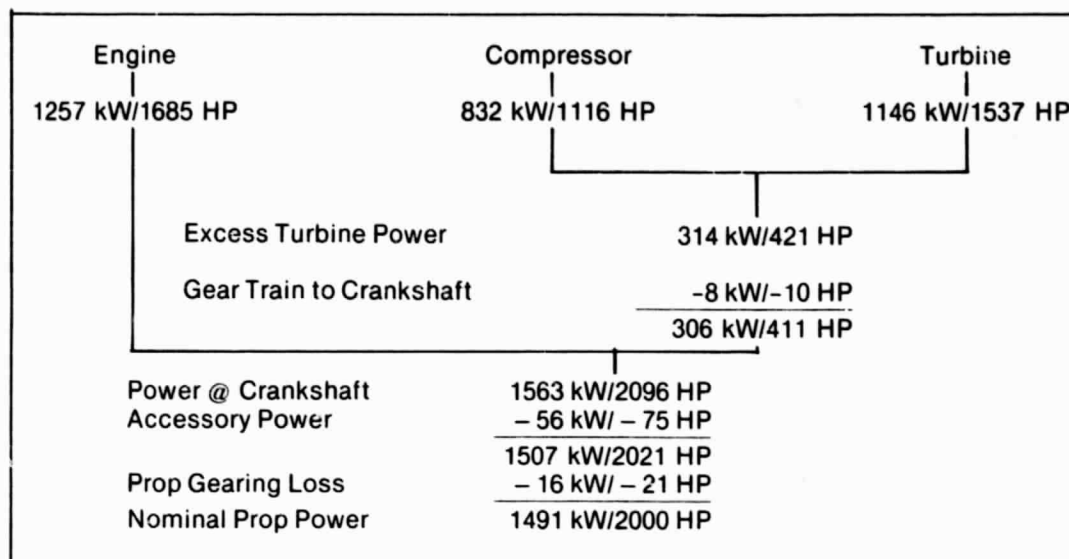


FIGURE 3-9 — POWER SCHEMATIC 100% CRUISE POWER @ 4572m (15000 FT.) ALTITUDE

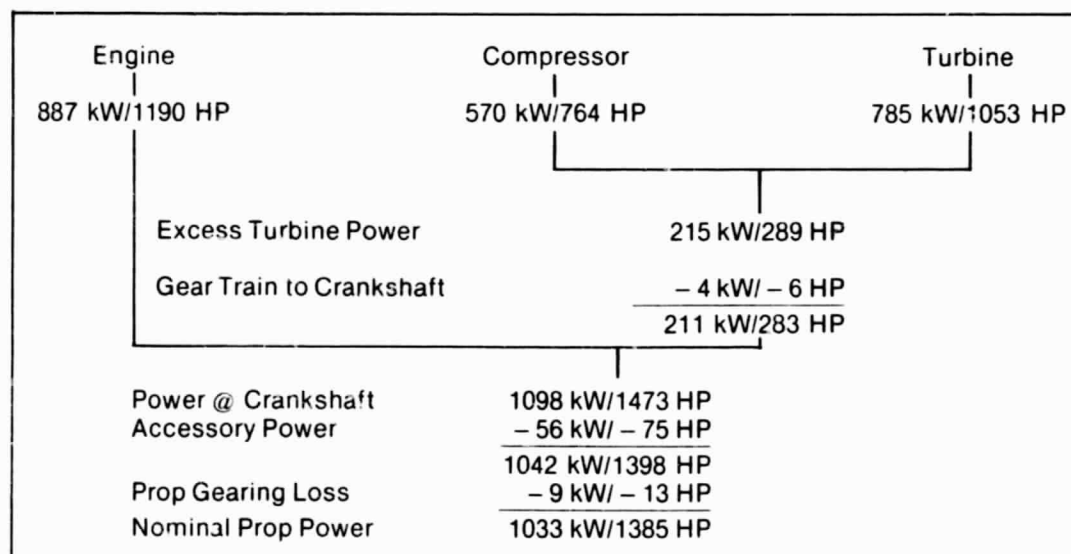


FIGURE 3-10 — POWER SCHEMATIC 100% CRUISE POWER @ 7620m (25000 FT.) ALTITUDE

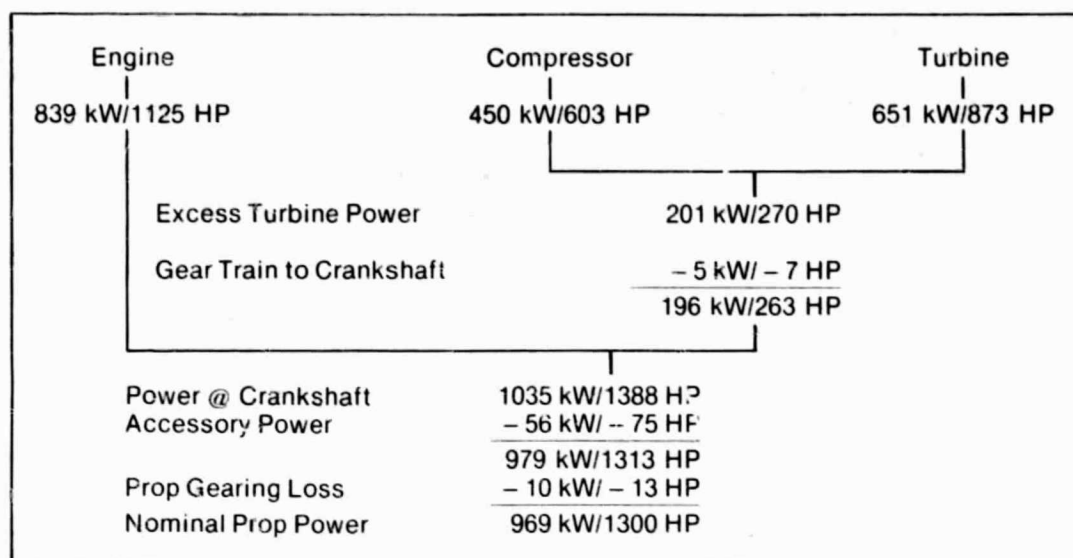


FIGURE 3-11 — POWER SCHEMATIC 65% CRUISE POWER @ 4572m (15000 FT.) ALTITUDE

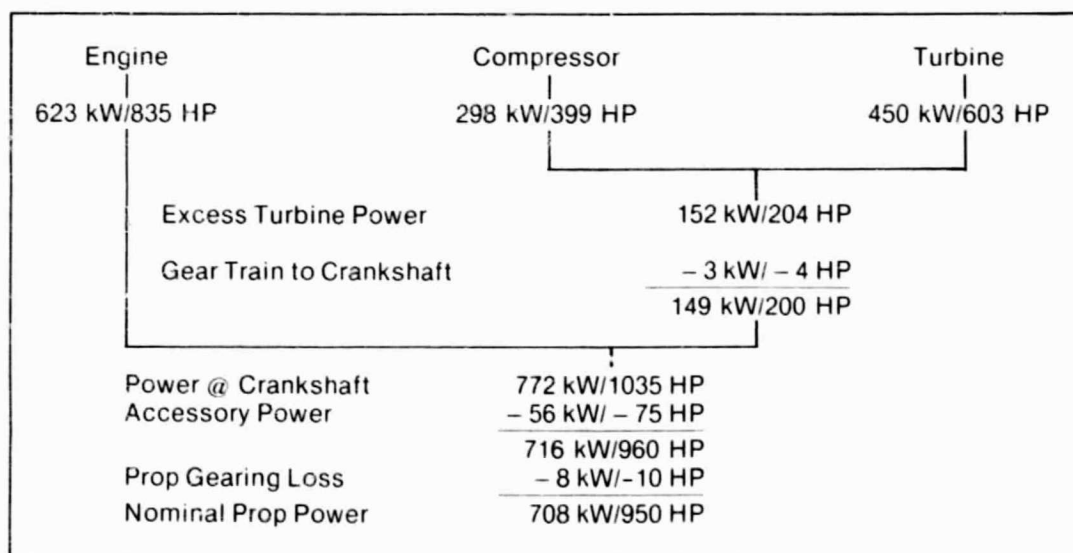


FIGURE 3-12 — POWER SCHEMATIC 65% CRUISE POWER @ 7620m (25000 FT.) ALTITUDE

### 3.2.6 EFFECT OF AIR AFTERCOOLING ON ENGINE PERFORMANCE

A study was made to investigate the effect of the aftercooler in the proposed engine configuration. The general purpose of an aftercooler is to reduce the temperature of the air out of the compressor and thus increase the induction air density in the intake manifold. However, the same density effect can be obtained without aftercooling by an increase of the intake manifold pressure. Table III shows a comparison of operation with and without an aftercooler for the 100% power condition at 4572m (15000 ft.) altitude for the same engine.

Common parameters are engine fuel flow and air density in the intake manifold.

**TABLE III**  
**Effect of Aftercooling on an Adiabatic Cycle**

|                             |           | No Aftercooling | With Aftercooling |
|-----------------------------|-----------|-----------------|-------------------|
| Piston Engine Displacement  | l         | 12.673          | 12.673            |
|                             | cu. in.   | 773.36          | 773.36            |
| Fuel Flow                   | kg/h      | 271             | 271               |
|                             | lb/h      | 598             | 598               |
| Compressor Inlet Press.     | bar       | .72             | .72               |
|                             | psi       | 10.44           | 10.44             |
| Compressor Inlet Temp       | °C        | 4               | 4                 |
|                             | °F        | 39              | 39                |
| Compressor Pressure Ratio   |           | 8.00:1          | 5.91:1            |
| Compressor Discharge Press. | bar       | 5.76            | 4.26              |
|                             | psi       | 83.52           | 61.73             |
| Compressor Discharge Temp.  | °C        | 263             | 225               |
|                             | °F        | 504             | 436               |
| Press. Drop In Aftercooler  | bar       |                 | .04               |
|                             | psi       |                 | .58               |
| Intake Manifold Press.      | bar       | 5.76            | 4.22              |
|                             | psi       | 83.52           | 61.15             |
| Temp. Drop in Aftercooler   | °C        |                 | 109               |
|                             | °F        |                 | 196               |
| Intake Manifold Temp        | °C        | 229             | 116               |
|                             | °F        | 504             | 240               |
| Intake Manifold Density     | kg/       | .00375          | .00378            |
|                             | lb/cu. ft | .234            | .236              |
| Air/Fuel Ratio — Trapped    |           | 24.4            | 24.4              |
| Max. Combustion Press       | bar       | 156.31          | 118.66            |
|                             | psi       | 2267            | 1721              |

**TABLE III (Continued)**  
**Effect of Aftercooling on an Adiabatic Cycle**

|                               |          | No Aftercooling | With Aftercooling |
|-------------------------------|----------|-----------------|-------------------|
| Max. Combustion Temp.         | °C       | 2241            | 1853              |
|                               | °F       | 4066            | 3367              |
| IMEP                          | bar      | 16.57           | 15.81             |
|                               | psi      | 240.3           | 229.3             |
| BMEP                          | bar      | 14.87           | 14.23             |
|                               | psi      | 215.7           | 206.4             |
| Piston Engine Power           | kW       | 1257            | 1204              |
|                               | HP       | 1685            | 1615              |
| Piston Engine BSFC            | g/kWh    | 216             | 225               |
|                               | lb/HPH   | .355            | .370              |
| Compressor Air Flow           | kg/s     | 3.15            | 3.15              |
|                               | lb/s     | 6.95            | 6.95              |
| Compressor Power              | kW       | 832             | 711               |
|                               | HP       | 1116            | 954               |
| Turbine Press. Ratio          |          | 8.00:1          | 5.85:1            |
| Turbine Inlet Temp.           | °C       | 603             | 435               |
|                               | °F       | 1117            | 814               |
| Turbine Gas Flow              | kg/s     | 3.23            | 3.23              |
|                               | lb/s     | 7.12            | 7.12              |
| Turbine Power                 | kW       | 1146            | 817               |
|                               | HP       | 1537            | 1095              |
| Excess Turbine Power          | kW       | 314             | 105               |
|                               | HP       | 421             | 141               |
| Piston Engine Power           | kW       | 1257            | 1204              |
|                               | HP       | 1685            | 1615              |
| Losses & Accessory Power      | kW       | 79              | 72                |
|                               | HP       | 106             | 96                |
| Nominal Propeller Power       | kW       | 1491            | 1238              |
|                               | HP       | 2000            | 1660              |
| Aftercooler Cooling Loss      | kcal/min |                 | 5004              |
|                               | BTU/min  |                 | 19858             |
| Heat Recovery Rate in Turbine | %        |                 | 55                |
| Equivalent Cooling Power      | kW       |                 | 192               |
|                               | HP       |                 | 257               |

The loss of compounded engine power in the case of an aftercooled engine (1238 vs. 1491 kW) is largely accounted for by the reduction of energy in the air in the aftercooler (192 kW). It shows that better overall fuel economy is obtained without aftercooling (with uncooled cylinders) and turbocompounding.

Other conclusions that follow from this analysis are:

1. The non-aftercooled cycle requires a higher compressor pressure ratio in order to obtain the same engine air flow.
2. The non-aftercooled cycle results in higher firing pressures.
3. The non-aftercooled cycle results in higher combustion temperatures due to the higher induction air temperature and thus may require different cylinder and piston top materials.
4. The reduced compounded power of the aftercooled cycle (1238 vs. 1491 kW) must be compensated for by a larger piston engine and turbine in order to develop the same overall power.

### 3.2.7 ALTITUDE PERFORMANCE DATA UP TO 7620m (25000 FT.)

1. Performance summary.

Table IV is a summary of the performance data shown in Table II.

**TABLE IV**  
**Summarized 1491 kW Performance Parameters**

| Altitude           | m<br>ft   | Takeoff   | 100% Power    |               | 65% Power     |               |
|--------------------|-----------|-----------|---------------|---------------|---------------|---------------|
|                    |           | Sea Level | 4572<br>15000 | 7620<br>25000 | 4572<br>15000 | 7620<br>25000 |
| Assumed Airspeed   | km/h      |           | 696           | 691           | 561           | 568           |
|                    | knots     |           | 376           | 373           | 303           | 307           |
|                    | Mach. No. |           | .60           | .62           | .48           | .51           |
| Nominal Prop Power | kW        | 1491      | 1491          | 1033          | 969           | 708           |
|                    | HP        | 2000      | 2000          | 1385          | 1300          | 950           |
| Prop Speed         | *RPM      | 1615      | 1615          | 1615          | 1211          | 1211          |
| Engine Speed       | RPM       | 4000      | 4000          | 4000          | 3000          | 3000          |
| Fuel Flow          | kg/h      | 306       | 271           | 191           | 176           | 131           |
|                    | lb/h      | 675       | 598           | 422           | 388           | 288           |
| Compounded BSFC    | g/kWh     | 205       | 182           | 185           | 182           | 185           |
|                    | lb/HPh    | .338      | .299          | .305          | .298          | .303          |

\*The choice of the propeller speed is based on a propeller tip speed at .8M and a diameter of 3.05m (10 ft.).

The sonic velocity at 4572m (15000 ft.) is 322.5 m/s (1058 fps)

Propeller tip speed = 258 m/s (846.5 fps)  
 Propeller speed = 1615 RPM at 4000 engine RPM  
 Propeller gear reduction = 2.477:1

## 2. Propeller shaft horsepower versus engine speed and altitude.

### A. Full load prop torque at sea level.

The following part load performance data are based on full load engine power, i.e., the maximum power that the power plant can produce at any engine speed. Two typical points on the torque curve are:

- The rated torque which is the maximum torque at 4000 engine RPM.
- The maximum torque, which is estimated to be 5% above the rated torque and occurs at 75% of the rated speed (3000 RPM).

The torque and power values are shown in Table V.

**TABLE V**  
**Full Load Power at Sea Level**

| Engine<br>RPM | Propeller<br>RPM | Propeller Torque |         | Propeller Power |      |
|---------------|------------------|------------------|---------|-----------------|------|
|               |                  | N.m              | Ft. Lb. | kW              | HP   |
| 4000          | 1615             | 8819             | 6504    | 1491            | 2000 |
| 3500          | 1413             | 9149             | 6747    | 1353            | 1815 |
| 3000          | 1211             | 9270             | 6836    | 1175            | 1576 |
| 2500          | 1009             | 9068             | 6687    | 958             | 1285 |

### B. Altitude effect.

The engine is flat rated (constant power) from sea level to 4572m (15000 ft.). This altitude was a study guideline. The flat rating could have been designed up to higher altitudes since the turbocompressor is not a limiting factor.

The power above 4572m is reduced due to the specific design of the turbine machinery. The maximum obtainable power at 7620m (25000 ft.) is 887 kW (1190 HP).

Table VI and Figure 3-13 show the maximum power at sea level and altitude at various engine speeds.

**TABLE VI**  
**Full Load Power at Sea Level and Altitude**

| Engine | RPM<br>Prop | Propeller Power |      |                  |      |                  |      |
|--------|-------------|-----------------|------|------------------|------|------------------|------|
|        |             | Sea Level       |      | 4572m (15000 ft) |      | 7620m (25000 ft) |      |
|        |             | kW              | HP   | kW               | HP   | kW               | HP   |
| 4000   | 1615        | 1491            | 2000 | 1491             | 2000 | 1033             | 1385 |
| 3500   | 1413        | 1353            | 1815 | 1353             | 1815 | 937              | 1257 |
| 3000   | 1211        | 1175            | 1576 | 1175             | 1576 | 814              | 1091 |
| 2500   | 1009        | 958             | 1285 | 958              | 1285 | 664              | 890  |

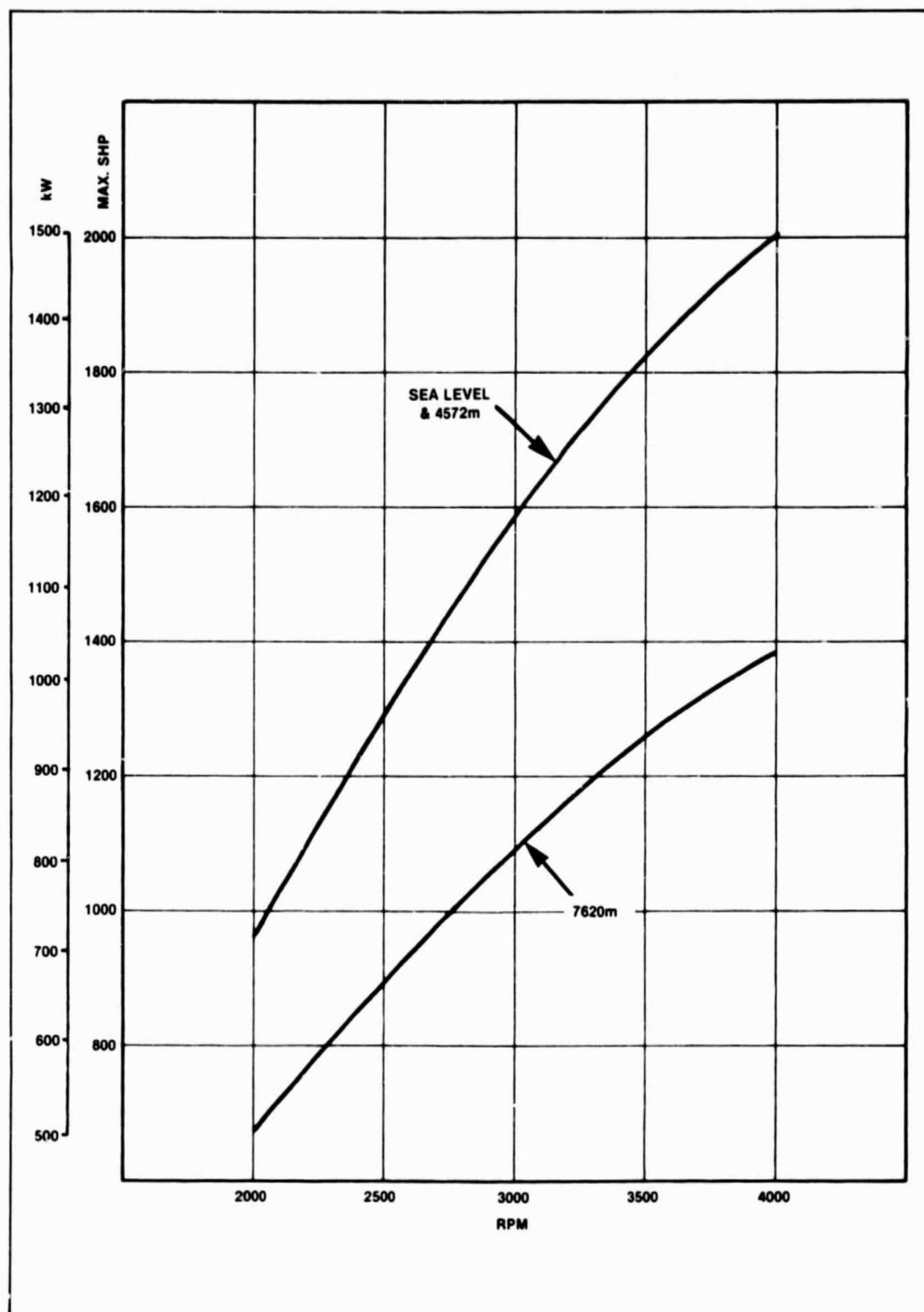


FIGURE 3-13 — 1491 kW COMMUTER AIRCRAFT DIESEL MAXIMUM SHP VERSUS RPM

### C. Fuel flow vs. RPM and altitude.

Table VII shows the sea level fuel flows at maximum power at various engine speeds.

- The propeller powers were taken from Table VI.
- The crankshaft power at 4000 RPM is taken from Figure 3-8. A correction was made for reduced gearing losses at lower engine speeds.
- The net turbine power at 4000 engine RPM is taken from Figure 3-8. The optimum turbine match was arbitrarily selected at peak 1491 kW (2000 HP) power but could have been chosen at a different load point. Lower turbine efficiencies at lower engine speeds thus result in a reduced contribution of the turbine power to the overall power. This contribution becomes negative below 2500 engine RPM, i.e., a part of the piston engine power will be required to drive the compressor.
- The piston engine BSFC and the fuel flow at 4000 RPM are taken from Table II. Part load test data of the TCM/GPD AVCR 1360 air-cooled diesel engine were used to proportion the BSFC's at lower engine speeds and loads.

**TABLE VII**  
**Fuel Flow at Sea Level at Max. SHP**

| RPM  | Prop<br>kW<br>HP | Cranksh.<br>kW<br>HP | Turbine |              | Engine<br>kW<br>HP | Piston<br>Engine BSFC<br>g/kWh<br>lb/HPh | Fuel Flow<br>kg/h<br>lb/h | Compounded<br>BSFC<br>g/kWh<br>lb/HPh |
|------|------------------|----------------------|---------|--------------|--------------------|--|---------------------------|---------------------------------------|
|      |                  |                      | % Total | Net kW<br>HP |                    |  |                           |                                       |
| 4000 | 1491             | 1528                 | 12.5    | 184          | 1344               | 228                                      | 306                       | 205                                   |
|      | 2000             | 2050                 |         | 247          | 1803               | .375                                     | 675                       | .338                                  |
| 3500 | 1353             | 1393                 | 9.0     | 125          | 1268               | 219                                      | 278                       | 205                                   |
|      | 1815             | 1868                 |         | 168          | 1700               | .360                                     | 612                       | .337                                  |
| 3000 | 1175             | 1213                 | 5.0     | 60           | 1153               | 216                                      | 249                       | 212                                   |
|      | 1576             | 1627                 |         | 81           | 1546               | .355                                     | 549                       | .348                                  |
| 2500 | 958              | 994                  | 0       | 0            | 994                | 219                                      | 218                       | 228                                   |
|      | 1285             | 1333                 |         |              | 1333               | .360                                     | 480                       | .374                                  |

The fuel flows at 4572m (15000 ft.) and 7620m (25000 ft.) altitude are shown in the Tables VIII and IX and were derived in a similar manner to that for sea level.



**TABLE VIII**  
**Fuel Flow at 4572m (15000 ft.) at Max. SHP**

| RPM  | Prop<br>kW<br>HP | Cranksh.<br>kW<br>HP | Turbine |              | Engine<br>kW<br>HP | Piston<br>Engine BSFC<br>g/kWh<br>lb/HPh | Fuel Flow<br>kg/h<br>lb/h | Compounded<br>BSFC<br>g/kWh<br>lb/HPh |
|------|------------------|----------------------|---------|--------------|--------------------|--|---------------------------|---------------------------------------|
|      |                  |                      | % Total | Net kW<br>HP |                    |  |                           |                                       |
| 4000 | 1491             | 1563                 | 19.6    | 306          | 1257               | 216                                      | 271                       | 182                                   |
|      | 2000             | 2096                 |         | 411          | 1685               | .355                                     | 598                       | .299                                  |
| 3500 | 1353             | 1423                 | 18.0    | 256          | 1167               | 213                                      | 249                       | 184                                   |
|      | 1815             | 1908                 |         | 343          | 1565               | .350                                     | 548                       | .302                                  |
| 3000 | 1175             | 1243                 | 16.0    | 199          | 1044               | 213                                      | 222                       | 189                                   |
|      | 1576             | 1667                 |         | 267          | 1400               | .350                                     | 490                       | .311                                  |
| 2500 | 958              | 1024                 | 13.0    | 133          | 891                | 219                                      | 195                       | 204                                   |
|      | 1285             | 1373                 |         | 178          | 1195               | .360                                     | 430                       | .335                                  |

**TABLE IX**  
**Fuel Flow at 7620m (25000 ft.) at Max. SHP**

| RPM  | Prop<br>kW<br>HP | Cranksh.<br>kW<br>HP | Turbine |              | Engine<br>kW<br>HP | Piston<br>Engine BSFC<br>g/kWh<br>lb/HPh | Fuel Flow<br>kg/h<br>lb/h | Compounded<br>BSFC<br>g/kWh<br>lb/HPh |
|------|------------------|----------------------|---------|--------------|--------------------|--|---------------------------|---------------------------------------|
|      |                  |                      | % Total | Net kW<br>HP |                    |  |                           |                                       |
| 4000 | 1033             | 1098                 | 19.2    | 211          | 887                | 216                                      | 191                       | 185                                   |
|      | 1385             | 1473                 |         | 283          | 1190               | .355                                     | 422                       | .305                                  |
| 3500 | 937              | 1003                 | 17.5    | 175          | 828                | 207                                      | 171                       | 182                                   |
|      | 1257             | 1345                 |         | 235          | 1110               | .340                                     | 377                       | .300                                  |
| 3000 | 814              | 878                  | 15.5    | 136          | 742                | 207                                      | 153                       | 188                                   |
|      | 1091             | 1177                 |         | 182          | 995                | .340                                     | 338                       | .310                                  |
| 2500 | 664              | 726                  | 12.5    | 91           | 635                | 213                                      | 135                       | 203                                   |
|      | 890              | 974                  |         | 122          | 852                | .350                                     | 298                       | .335                                  |

Note that the contribution of the turbine power to the overall power is higher at altitudes above sea level. This is due to the ram effect at the compressor inlet which reduces the required compressor power and to the lower ambient air pressure which results in increased turbine power.

Figure 3-14 shows fuel flows from the Tables VII, VIII and IX in graphical form.

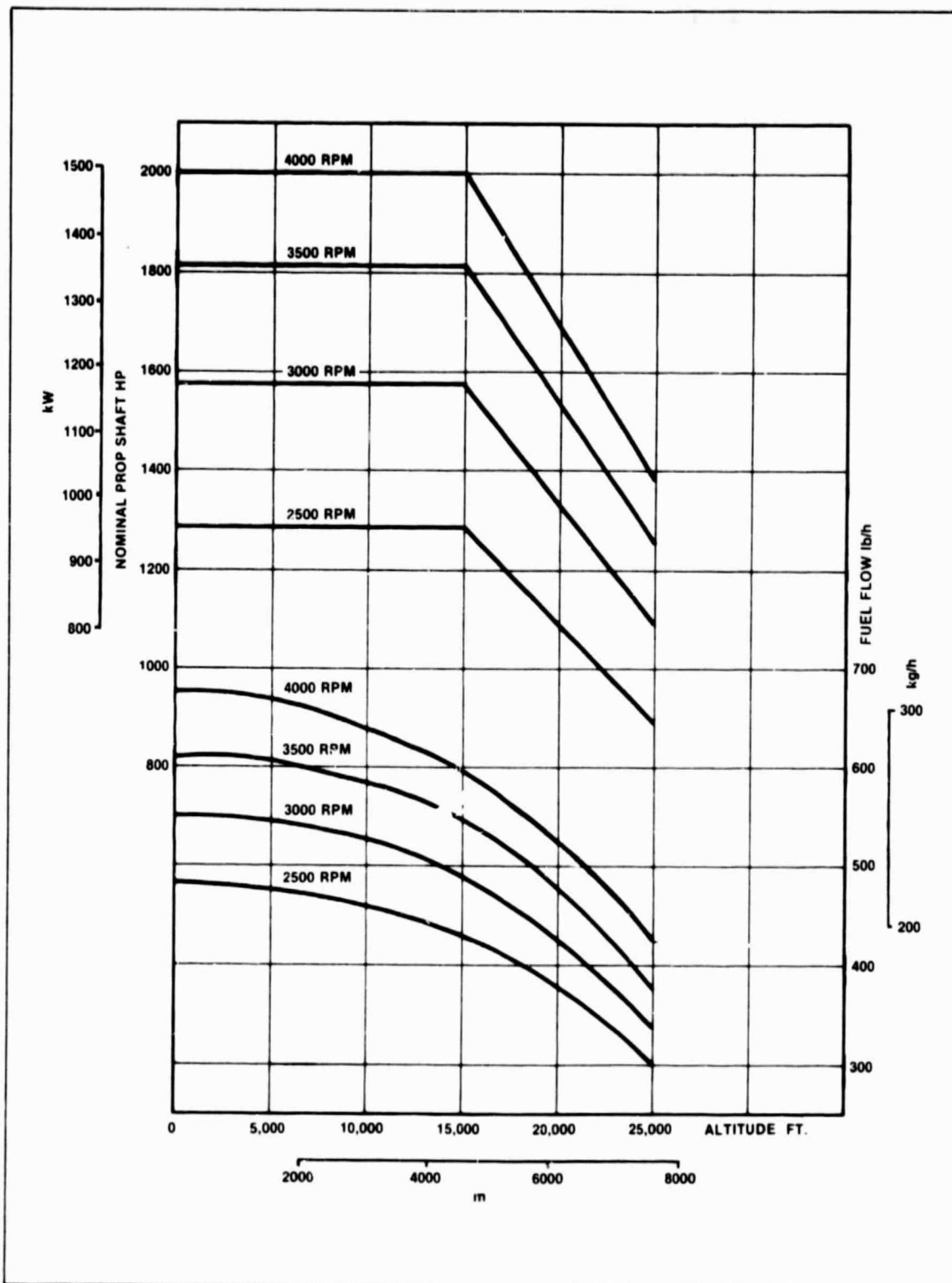


FIGURE 3-14 — 1491 kW COMMUTER AIRCRAFT DIESEL MAXIMUM SHP AND FUEL FLOW

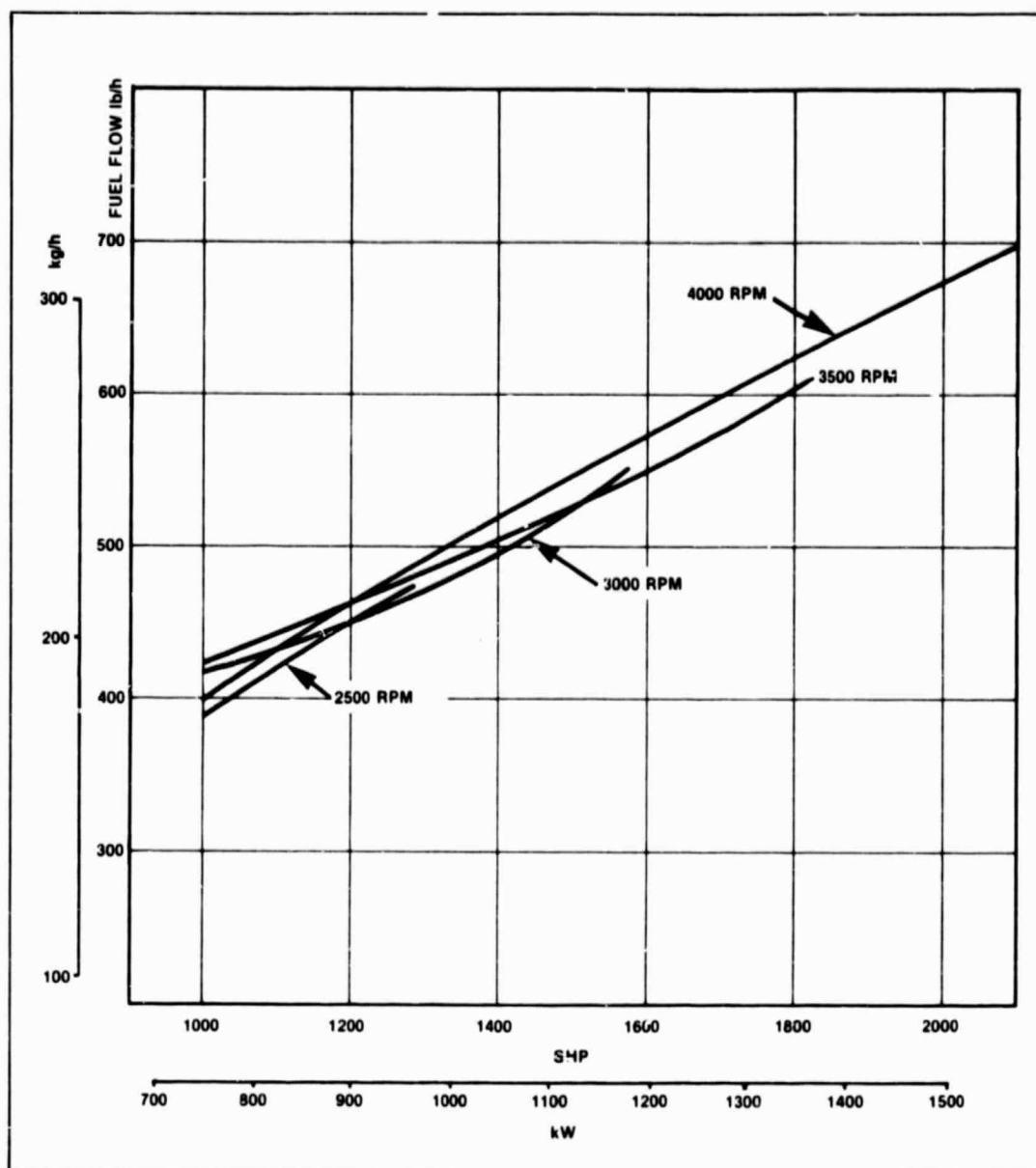


FIGURE 3-15 — 1491 kW COMMUTER AIRCRAFT DIESEL PART LOAD FUEL CONSUMPTION AT SEA LEVEL

### 3. Estimated fuel flow at idle RPM.

The values shown below are estimates of the idle fuel flow.

|                |      |                    |
|----------------|------|--------------------|
| Idle Speed     | 1000 | RPM                |
| FMEP           | 1.38 | bar (20 psi)       |
| Friction Power | 29   | kW (39 HP)         |
| Friction SFC   | 487  | g/kWh (.80 lb/HPh) |
| Idle Fuel Flow | 14   | kg/h (31 lb/h)     |

If 22 kW (30 HP) accessory power is included:

|              |     |                    |
|--------------|-----|--------------------|
| Engine Power | 51  | kW (69 HP)         |
| BSFC         | 456 | g/kWh (.75 lb/HPh) |
| Fuel Flow    | 24  | kg/h (52 lb/h)     |

### 4. Full and part load power settings.

#### A. Takeoff power at 32.5°C (90°F).

The previous power calculations are based on 15.0°C (59°F) ambient air temperature.

The power reduction of diesel engines due to elevated air temperatures is 1% per 5.56°C (10°F). Thus the corrected gross crankshaft power at 90°F (see Figure 3-8) is:

|                          |   |                   |
|--------------------------|---|-------------------|
| .969 x 1528              | = | 1481 kW (1986 HP) |
| Losses & Accessory Power | = | 37 kW (- 50 HP)   |
| Nominal Prop Power       | = | 1444 kW (1936 HP) |

#### B. Maximum climb power at ISA ambient conditions\* — see Table VI.

- The power plant is flat rated at 1491 kW (2000 SHP) up to 4572m (15000 ft.) altitude.
- Above 4572m (15000 ft.) the climb power will decrease linearly with altitude from 1491 kW (2000 HP) to 1033 kW (1385 HP) at 7620m (25000 ft.)

#### C. Partial power @ ISA ambient conditions.

The fuel flows were determined for the following power settings:

- #1 50% @ ISA conditions.
- #2 60% @ ISA conditions.
- #3 70% @ ISA conditions.
- #4 80% @ ISA conditions.
- #5 90% @ ISA conditions.

\*ISA — International Standard Atmosphere  
— Pressure 1.013 bar (29.92 in Hg)  
— Temperature 15°C (59°F)

The Figures 3-15 through 3-17 show the fuel flows as a function of the nominal propeller power, engine RPM and altitude. The end points of the curves represent the 100% power setting for that engine speed and altitude.

The RPM curves are too close together to draw conclusions on the optimum engine speed for a given power level.

### 3.3 Engine Physical Characteristics

A study was made of the engine weight, center of gravity and the overall dimensions.

#### 3.3.1 ENGINE WEIGHT ANALYSIS

A weight analysis was conducted of two versions of materials for the same engine performance. One version uses conventional materials and the second uses advanced lightweight material technologies.

A detailed weight analysis of the two versions is shown in Table X.

**TABLE X**  
**1491 kW (2000 HP) Weight Analysis**

| Component              | Weight   |      |              |      |
|------------------------|----------|------|--------------|------|
|                        | Advanced |      | Conventional |      |
|                        | kg       | lb   | kg           | lb   |
| Prop Gear Housing      | 19       | 41   | 23           | 51   |
| Crankshaft             | 33       | 73   | 33           | 73   |
| Prop Drive Gear        | 9        | 20   | 10           | 22   |
| Pinions                | 18       | 40   | 20           | 44   |
| Sun Gear on Crankshaft | 3        | 7    | 3            | 7    |
| Cylinders              | 91       | 200  | 91           | 200  |
| Pistons                | 33       | 72   | 44           | 96   |
| Piston Pins            | 9        | 20   | 9            | 20   |
| Connecting Rods        | 24       | 52   | 39           | 85   |
| Crankcase              | 15       | 32   | 18           | 40   |
| Intake Manifolds       | 18       | 40   | 23           | 50   |
| Exhaust Manifolds      | 17       | 38   | 17           | 38   |
| Accessory Drive Gears  | 4        | 9    | 5            | 10   |
| Injection System       | 36       | 80   | 36           | 80   |
| Governor               | 1        | 3    | 1            | 3    |
| Vacuum Pump            | 1        | 3    | 1            | 3    |
| Oil Pump               | 5        | 12   | 6            | 13   |
| Starter                | 27       | 60   | 27           | 60   |
| Generator              | 27       | 60   | 27           | 60   |
| Oil Cooler             | 14       | 30   | 14           | 30   |
| Compressor/Turbine     | 114      | 250  | 145          | 320  |
| Turbine Drive Gearing  | 23       | 50   | 27           | 60   |
| Balance of Parts       | 49       | 108  | 61           | 135  |
| Engine Weight — Dry    | 590      | 1300 | 680          | 1500 |
| Oil & Tank Weight      | 30       | 65   | 30           | 65   |
| Engine Weight — Wet    | 620      | 1365 | 710          | 1565 |

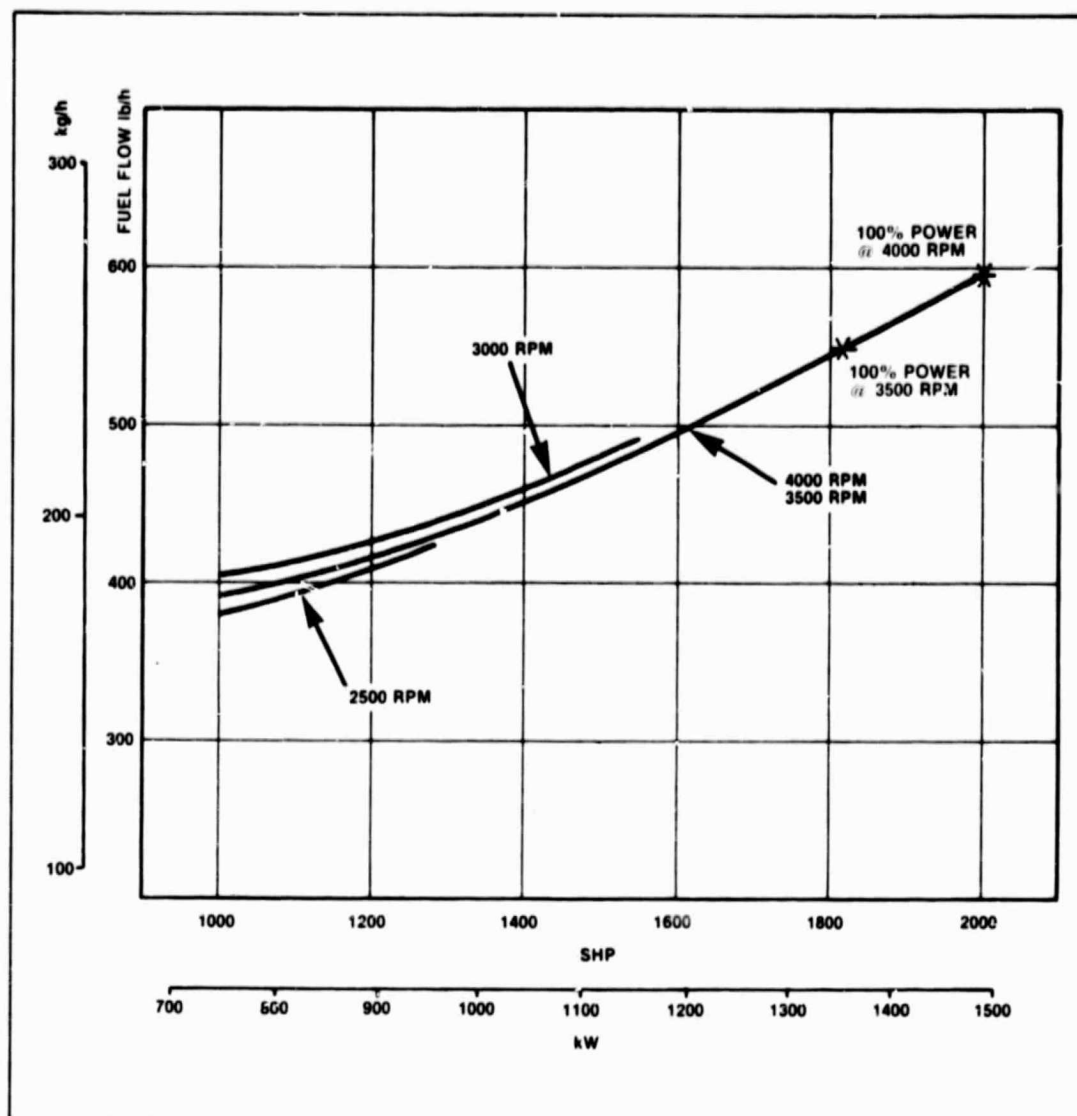


FIGURE 3-16 — 1491 kW COMMUTER AIRCRAFT DIESEL PART LOAD FUEL CONSUMPTION AT 4572m ALTITUDE

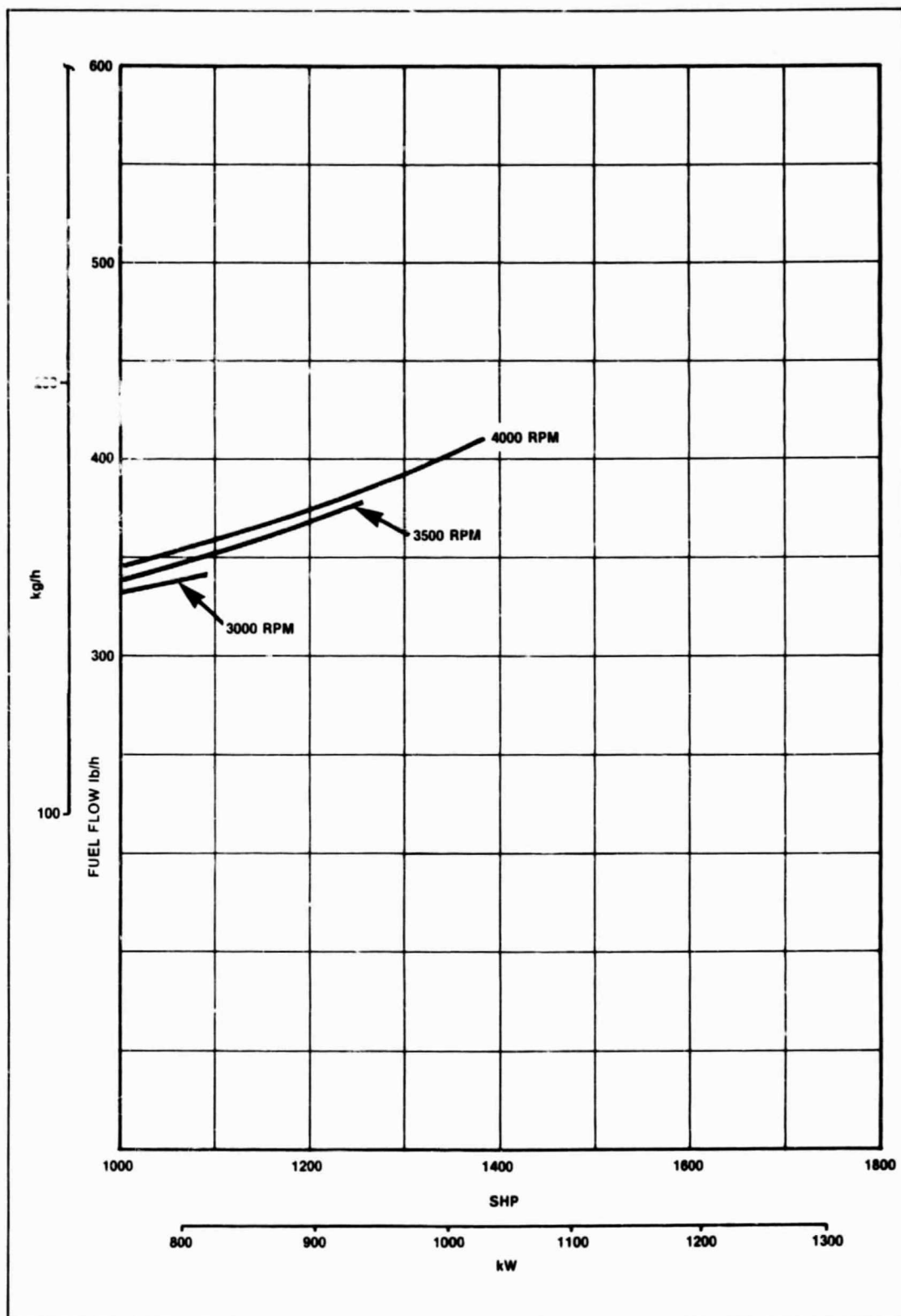


FIGURE 3-17 — 1491 kW COMMUTER AIRCRAFT DIESEL PART LOAD FUEL CONSUMPTION AT 7620m ALTITUDE

The specific weights, referenced to 1491 kW (2000 HP) net shaft power are:

|                        | kg/kW | lb/HP |
|------------------------|-------|-------|
| Advanced Materials     | .415  | .683  |
| Conventional Materials | .476  | .783  |

These numbers, although higher than for a turboprop engine, are extremely low for a diesel power plant. By comparison, the specific weight of the relatively low weight Napier Nomad engine was .71 kg/kW (1.17 lb/HP).

### 3.3.2 LOCATION OF THE ENGINE CENTER OF GRAVITY

The center of gravity was determined in two directions. It is assumed to be on the vertical axis of the engine.

1. Horizontally.

154mm (6.08") behind the centerline of the front row of cylinders.

2. Vertically.

87mm (3.44") below the crankshaft centerline.

### 3.3.3 ENGINE DIMENSIONS

The overall engine dimensions are:

|              |                     |                          |
|--------------|---------------------|--------------------------|
| Length       | 1490mm              | (58.62 in)               |
| Width        | 752mm               | (29.58 in)               |
| Height       | 900mm               | (35.41 in)               |
| Volume       | 1006dm <sup>3</sup> | (35.53 ft <sup>3</sup> ) |
| Frontal Area | 5026cm <sup>2</sup> | (799 in <sup>2</sup> )   |



## **4.0 DESIGN STUDY OF THE 895 kW (1200 SHP) ENGINE**

This engine is essentially a scaled down version of the 1491 kW (2000 HP) engine. Its features are:

- 6 cylinders in a two row, radial configuration.
- A high crankshaft speed
- Two-stroke cycle — Schnuerle scavenge system
- Insulated cylinders
- Turbocompounded
- No aftercooling
- 9:1 effective compression ratio
- Variable speed drive between turbine and piston engine
- High pressure injection system
- Open chamber combustion system
- Geared propeller drive
- Electronic controls

### **4.1 Engine Concept Design**

Three views and a partial section of the engine are shown in Figures 4-1 through 4-4.

The cylinders are arranged in two rows of three cylinders each. Two cylinders are shown upright in a vertical plane, the remaining cylinders are at a 30° angle with the horizontal plane. The engine has a very favorable profile with the turbomachinery located between two banks of cylinders. It was again decided, due to the high firing pressures, to design a crankshaft with two separate crank throws.

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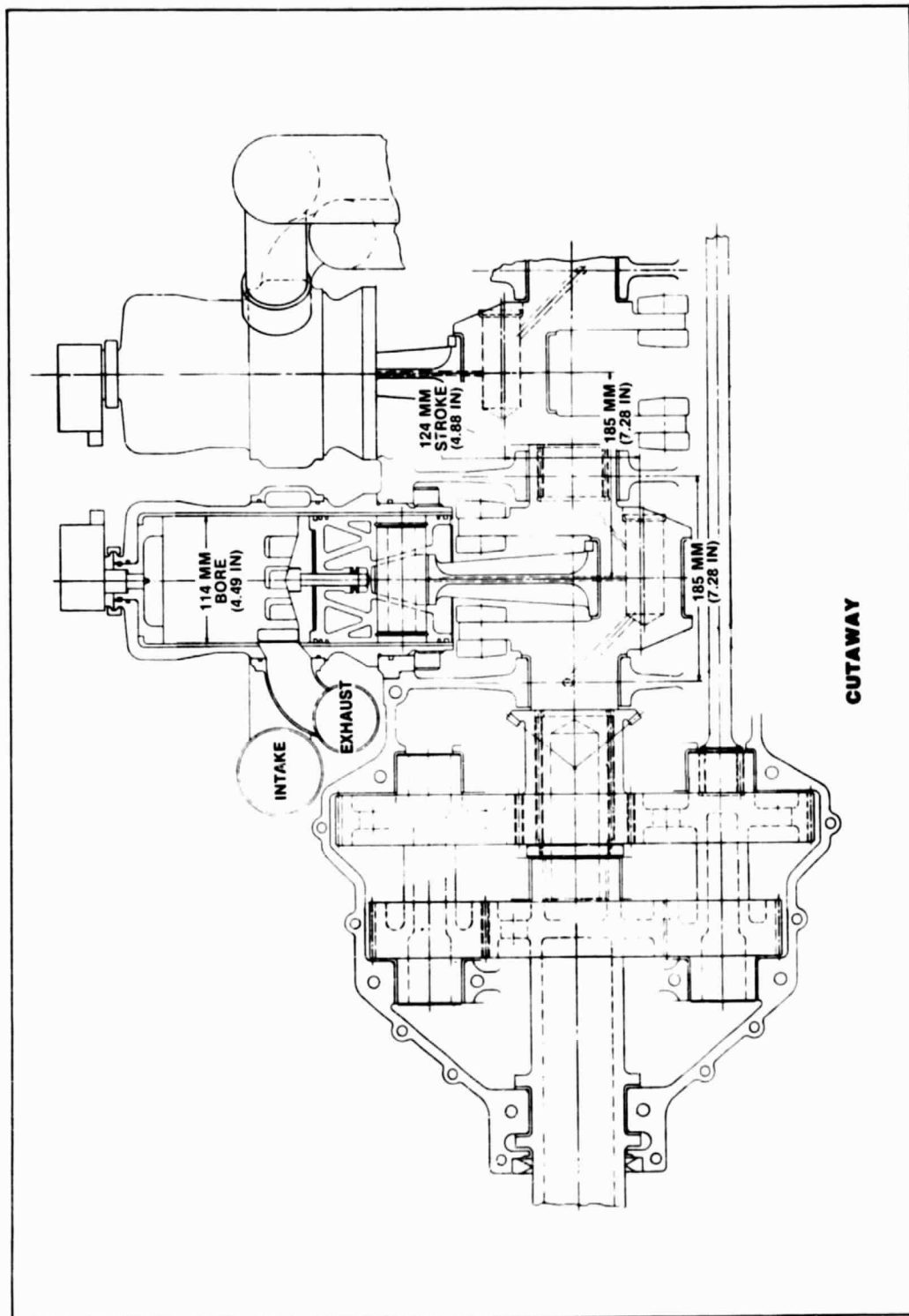


FIGURE 4-1 — 895 kW COMMUTER AIRCRAFT DIESEL - PARTIAL LONGITUDINAL SECTION

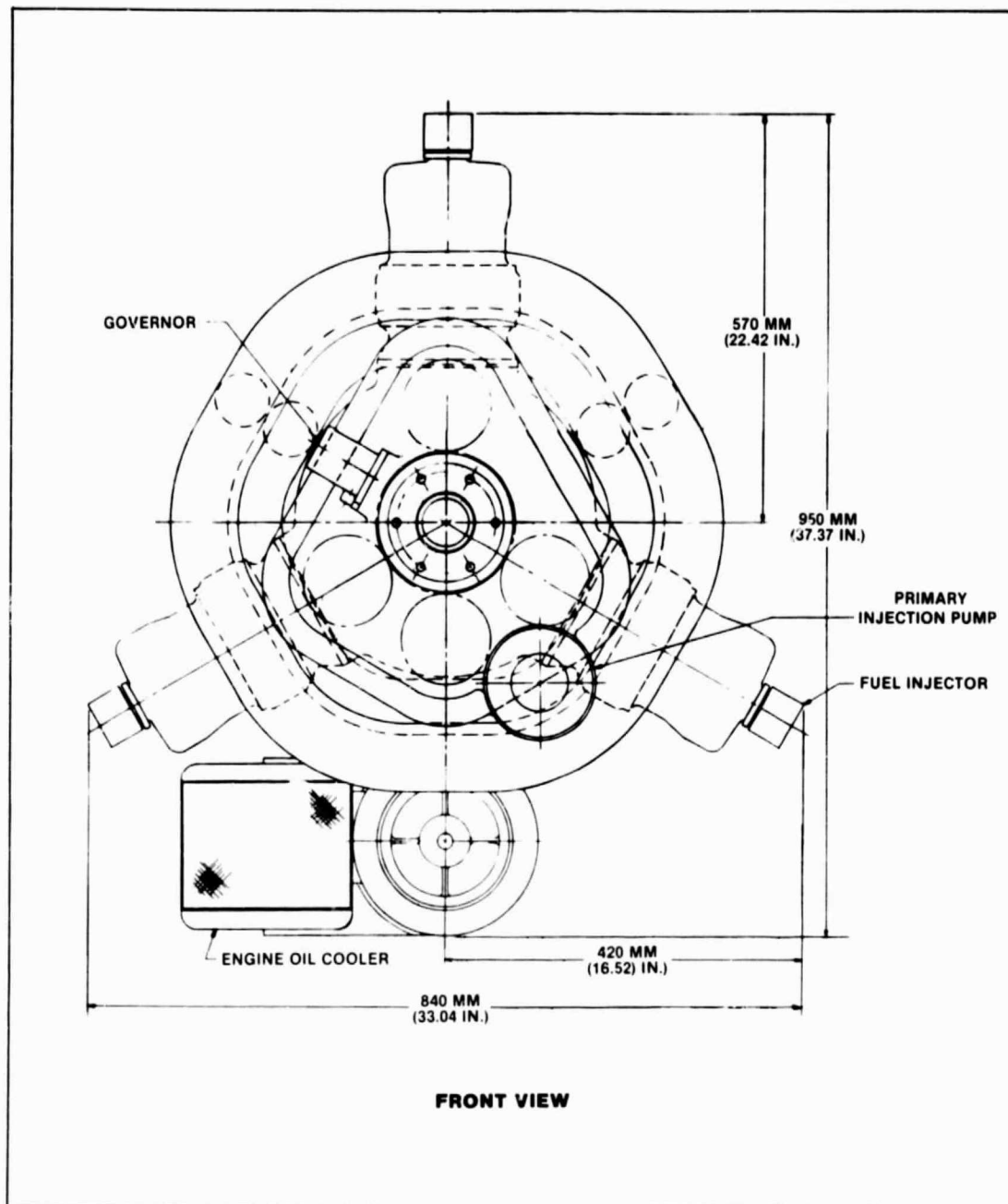


FIGURE 4-2 — 895 kW COMMUTER AIRCRAFT DIESEL - FRONT VIEW

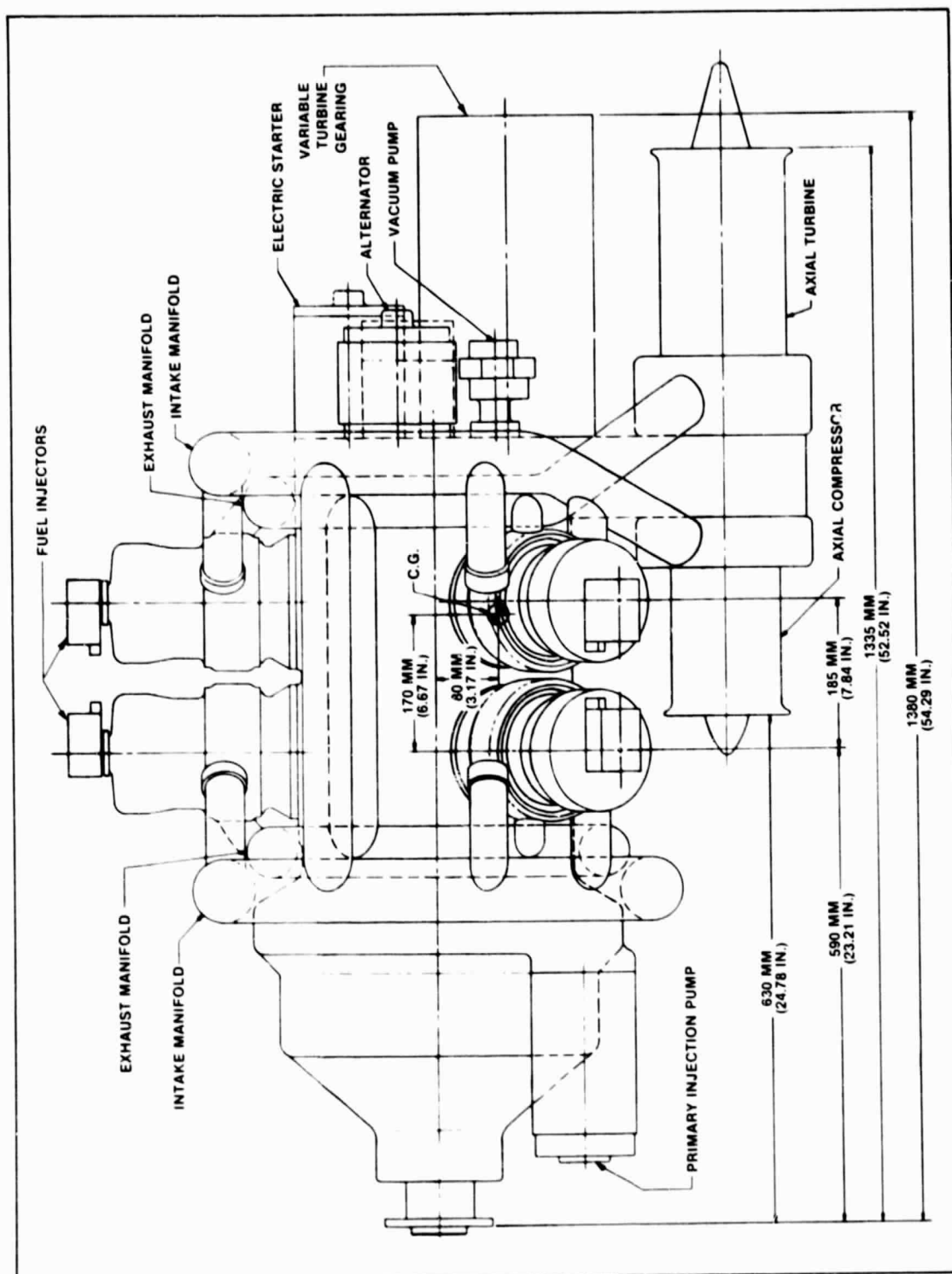


FIGURE 4-3 — 895 kW COMMUTER AIRCRAFT DIESEL - SIDE VIEW

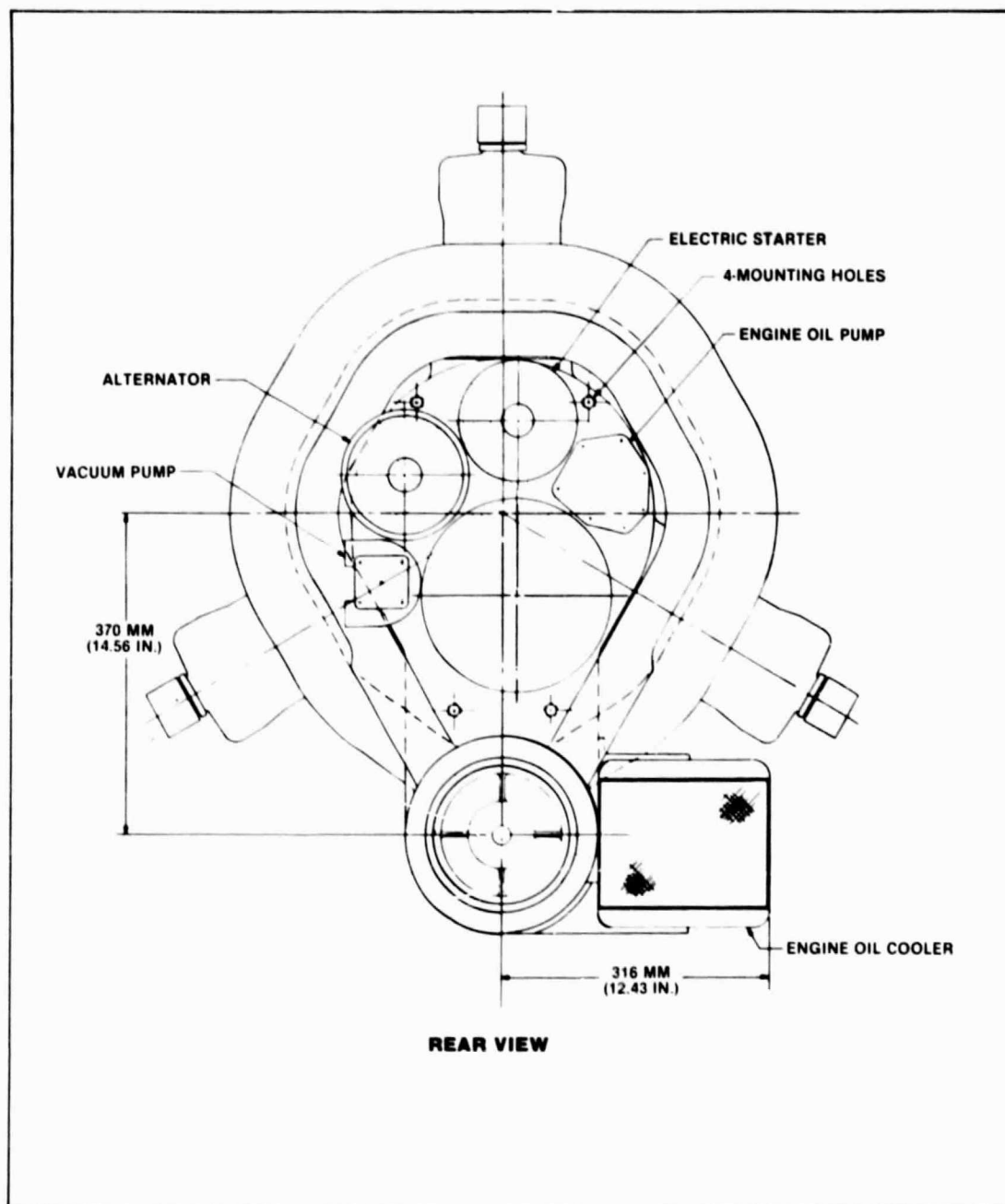


FIGURE 4-4 — 895 kW COMMUTER AIRCRAFT DIESEL - REAR VIEW

## 4.2 Engine Characteristics

The basic engine characteristics are:

|                               |                                       |
|-------------------------------|---------------------------------------|
| Number of Cylinders           | 6                                     |
| Cycle                         | 2 s.c.                                |
| Configuration                 | Radial/Compounded                     |
| Bore x Stroke                 | 114 x 124 mm<br>4.49 x 4.88 in.       |
| Displacement                  | 7.594 l<br>463.36 cu. in.             |
| Engine Speed                  | 4000 RPM                              |
| Piston Speed                  | 16.5 m/s<br>3255 fpm                  |
| Piston Engine Power @ Takeoff | 809 kW<br>1085 HP                     |
| BMEP @ Takeoff                | 15.98 bar<br>232 psi                  |
| Specific Power                | 106.5 kW/l<br>2.34 HP/in <sup>3</sup> |
| Propeller Speed               | 1615 RPM                              |

### 4.3 Power Schematics

Figures 4-5 through 4-9 show the compounded power schematics for five flight conditions:

- Takeoff
- 100% cruise power at 4572m (15000 ft.) and 7620m (25000 ft.) altitude.
- 65% cruise power at 4572m and 7620m altitude.

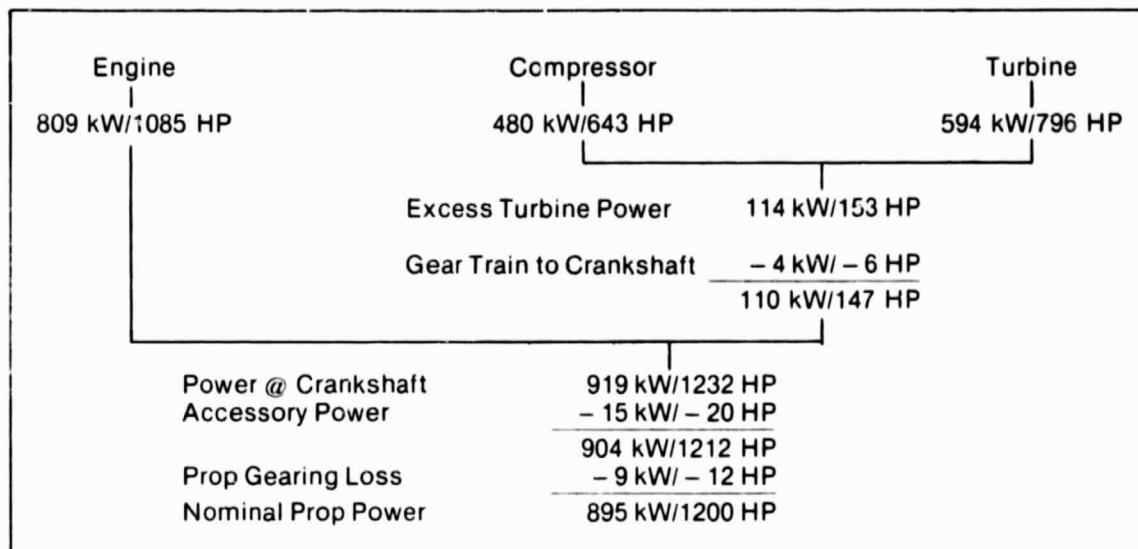


FIGURE 4-5 — POWER SCHEMATIC TAKEOFF MODE

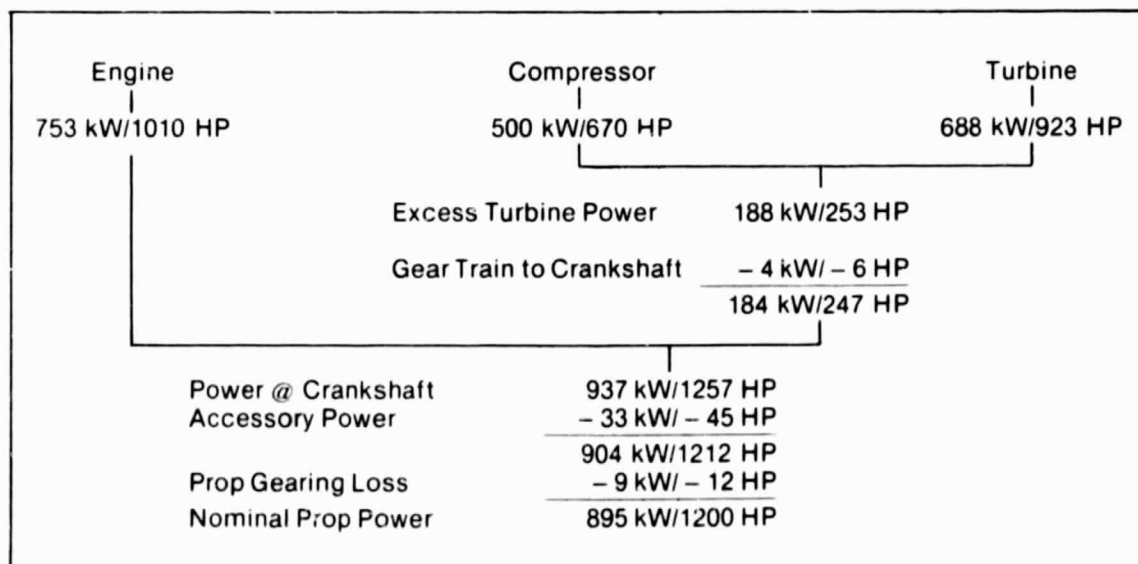


FIGURE 4-6 — POWER SCHEMATIC 100% CRUISE POWER @ 4572m (15000 FT.) ALTITUDE

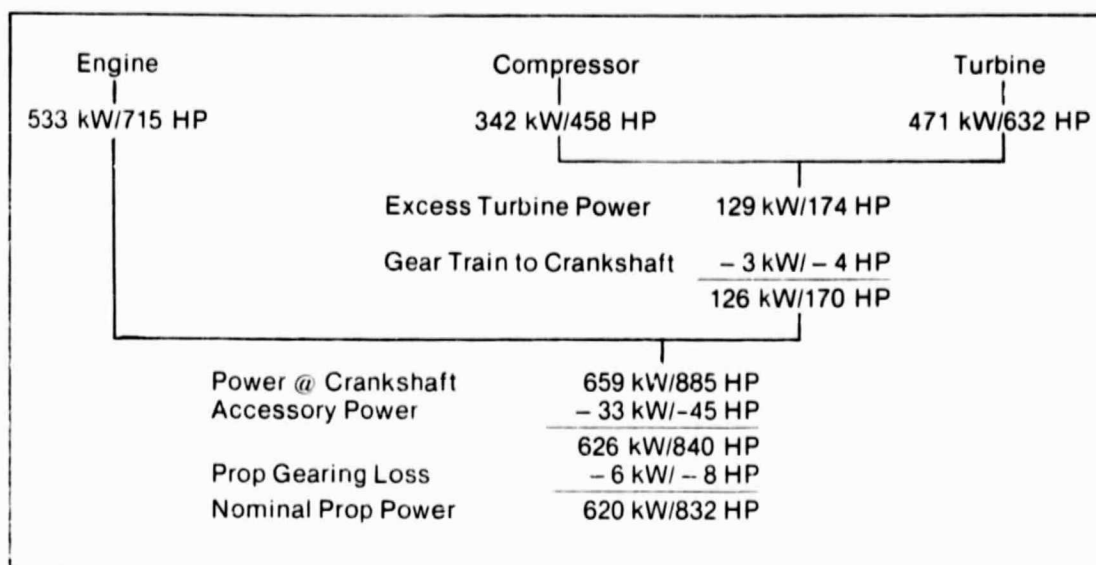


FIGURE 4-7 — POWER SCHEMATIC 100% CRUISE POWER @ 7620m (25000 FT.) ALTITUDE

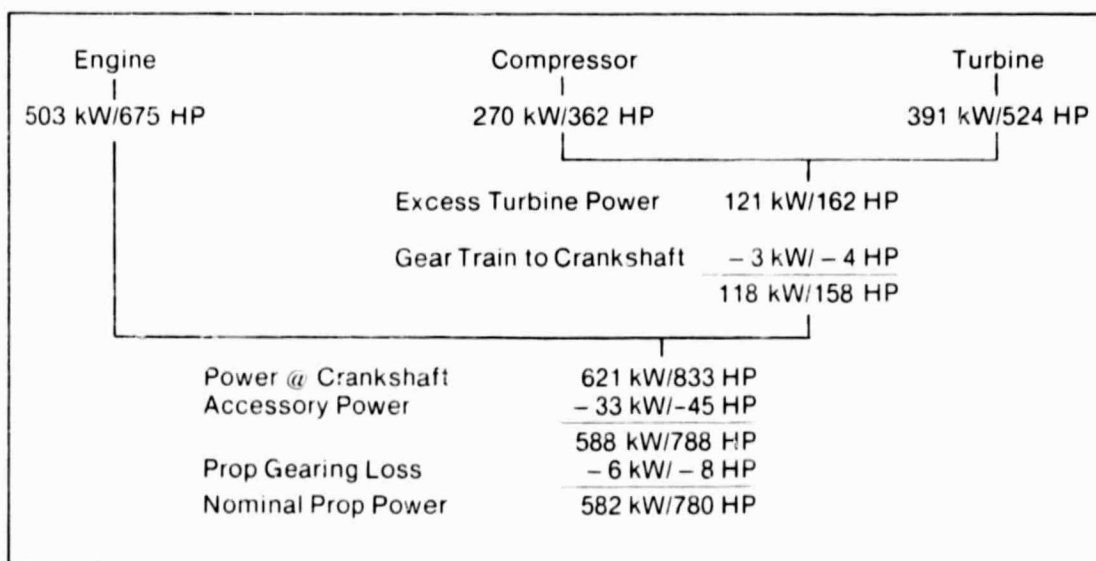


FIGURE 4-8 — POWER SCHEMATIC 65% CRUISE POWER @ 4572m (15000 FT.) ALTITUDE



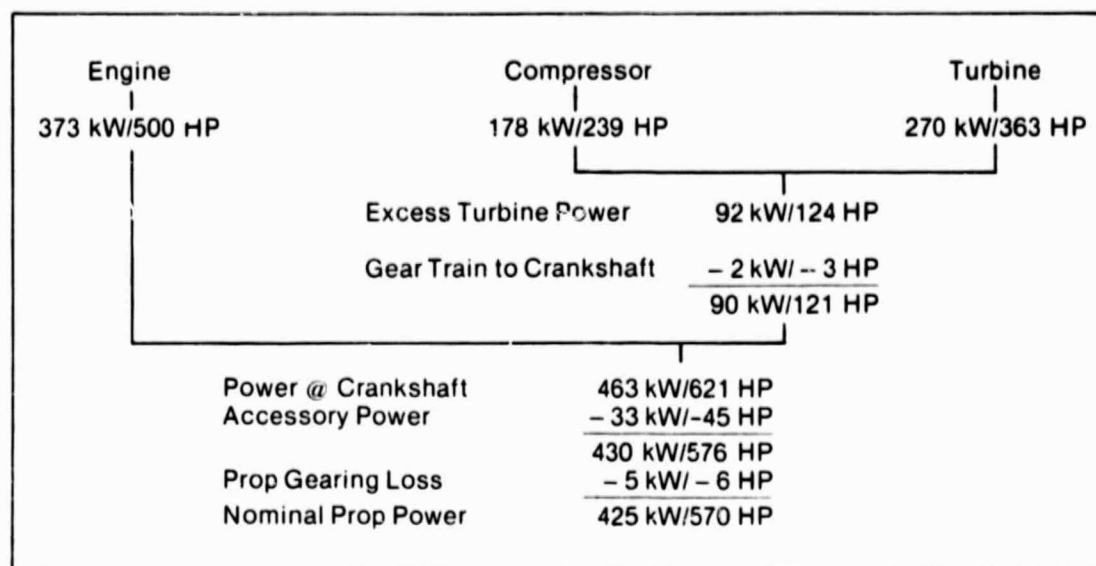


FIGURE 4-9 — POWER SCHEMATIC 65% CRUISE POWER @ 7620m (25000 FT.) ALTITUDE

#### 4.4 Performance Data Up to 7620m (25000 ft.) Altitude

##### 1. Performance summary.

Table XI is a summary of the engine performance parameters.

**TABLE XI**  
**Summarized 895 kW Performance Parameters**

| Altitude           | m<br>ft   | Takeoff<br>Sea Level | 100% Power    |               | 65% Power     |               |
|--------------------|-----------|----------------------|---------------|---------------|---------------|---------------|
|                    |           |                      | 4572<br>15000 | 7620<br>25000 | 4572<br>15000 | 7620<br>25000 |
| Assumed Airspeed   | km/h      |                      | 696           | 691           | 561           | 568           |
|                    | knots     |                      | 376           | 373           | 303           | 307           |
|                    | Mach. No. |                      | .60           | .62           | .48           | .51           |
| Nominal Prop Power | kW        | 895                  | 895           | 620           | 582           | 425           |
|                    | HP        | 1200                 | 1200          | 832           | 780           | 570           |
| Prop Speed*        | RPM       | 1615                 | 1615          | 1615          | 1211          | 1211          |
| Engine Speed       | RPM       | 4000                 | 4000          | 4000          | 3000          | 3000          |
| Fuel Flow          | kg/h      | 190                  | 167           | 117           | 110           | 79            |
|                    | lb/h      | 418                  | 369           | 257           | 243           | 175           |
| Compounded BSFC    | g/kWh     | 212                  | 187           | 189           | 189           | 186           |
|                    | lb/HPH    | .348                 | .308          | .309          | .312          | .307          |

\*The choice of the propeller speed is based on a propeller tip speed at .8m and a diameter of 3.05m (10 ft.).

##### 2. Propeller shaft horsepower versus engine speed and altitude.

##### A. Full load prop torque at sea level.

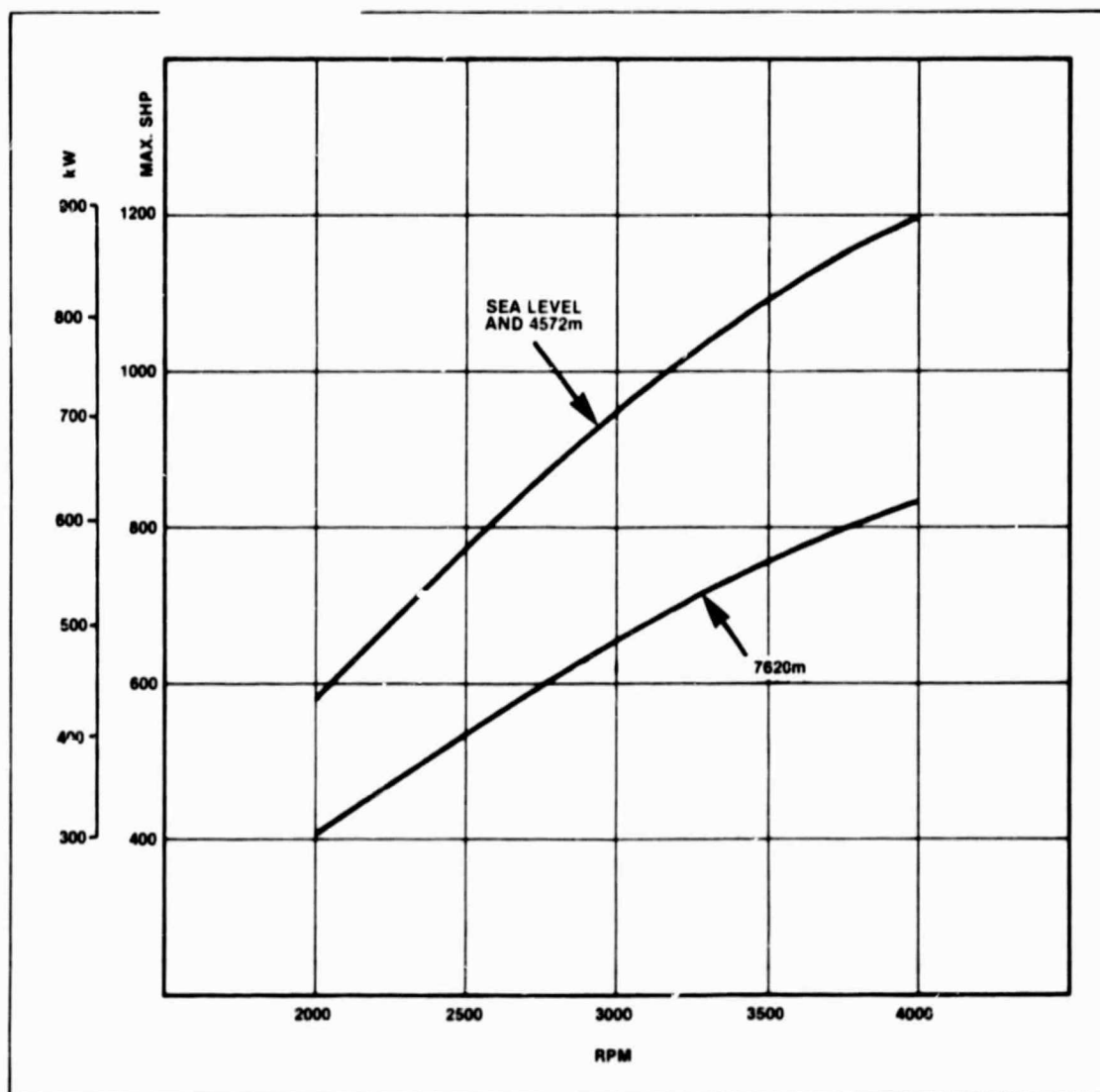
The full load torque and propeller power data shown in Table XII are based on a 5% torque rise characteristic at reduced speed. The maximum torque is at 3000 RPM.

**TABLE XII**  
**Full Load Power at Sea Level**

| Engine RPM | Propeller RPM | Prop Torque |       | Propeller Power |      |
|------------|---------------|-------------|-------|-----------------|------|
|            |               | N.m         | ft-lb | kW              | HP   |
| 4000       | 1615          | 5291        | 3902  | 895             | 1200 |
| 3500       | 1413          | 5489        | 4048  | 812             | 1089 |
| 3000       | 1211          | 5556        | 4097  | 705             | 945  |
| 2500       | 1009          | 5440        | 4012  | 575             | 771  |

**B. Altitude effect.**

The engine is flat rated from sea level to 4572m (15000 ft.). The power drops off above that altitude due to the characteristics of the turbine machinery. The maximum obtainable power at 7620m (25000 ft.) is 620 kW (832 HP). Table XIII and Figure 4-10 show the maximum power at sea level and altitude as a function of engine speed.



**FIGURE 4-10 — 895 kW COMMUTER AIRCRAFT DIESEL MAXIMUM SHP VERSUS RPM**

**TABLE XIII**  
**Full Load Power at Sea Level and Altitude**

| RPM    |      | Propeller Power |      |                   |      |                   |     |
|--------|------|-----------------|------|-------------------|------|-------------------|-----|
| Engine | Prop | Sea Level       |      | 4572m (15000 ft.) |      | 7620m (25000 ft.) |     |
|        |      | kW              | HP   | kW                | HP   | kW                | HP  |
| 4000   | 1615 | 895             | 1200 | 895               | 1200 | 620               | 832 |
| 3500   | 1413 | 812             | 1089 | 812               | 1089 | 563               | 755 |
| 3000   | 1211 | 705             | 945  | 705               | 945  | 488               | 655 |
| 2500   | 1009 | 575             | 771  | 575               | 771  | 399               | 535 |

C. Fuel flow vs. RPM and altitude.

Tables XIV, XV and XVI show the fuel flows at maximum power at various engine speeds for takeoff and cruise power conditions.

Figure 4-6 shows these tables in graphic form.

**TABLE XIV**  
**Fuel Flow at Sea Level at Max. SHP**

| RPM  | Prop<br>kW<br>HP | Cranksh.<br>kW<br>HP | Turbine |              | Engine<br>kW<br>HP | Piston<br>Engine BSFC<br>g/kWh<br>lb/HPh | Fuel Flow<br>kg/h<br>lb/h | Compounded<br>BSFC<br>g/kWh<br>lb/HPh |
|------|------------------|----------------------|---------|--------------|--------------------|--|---------------------------|---------------------------------------|
|      |                  |                      | % Total | Net kW<br>HP |                    |  |                           |                                       |
| 4000 | 895              | 919                  | 11.9    | 110          | 809                | 234                                      | 190                       | 212                                   |
|      | 1200             | 1232                 |         | 147          | 1085               | .385                                     | 418                       | .348                                  |
| 3500 | 812              | 835                  | 8.5     | 71           | 764                | 225                                      | 172                       | 212                                   |
|      | 1089             | 1120                 |         | 95           | 1025               | .370                                     | 379                       | .348                                  |
| 3000 | 705              | 726                  | 5.0     | 37           | 690                | 222                                      | 153                       | 217                                   |
|      | 945              | 947                  |         | 49           | 925                | .365                                     | 338                       | .358                                  |
| 2500 | 575              | 596                  | 0       | 0            | 596                | 225                                      | 134                       | 233                                   |
|      | 771              | 799                  |         | 0            | 799                | .370                                     | 296                       | .384                                  |

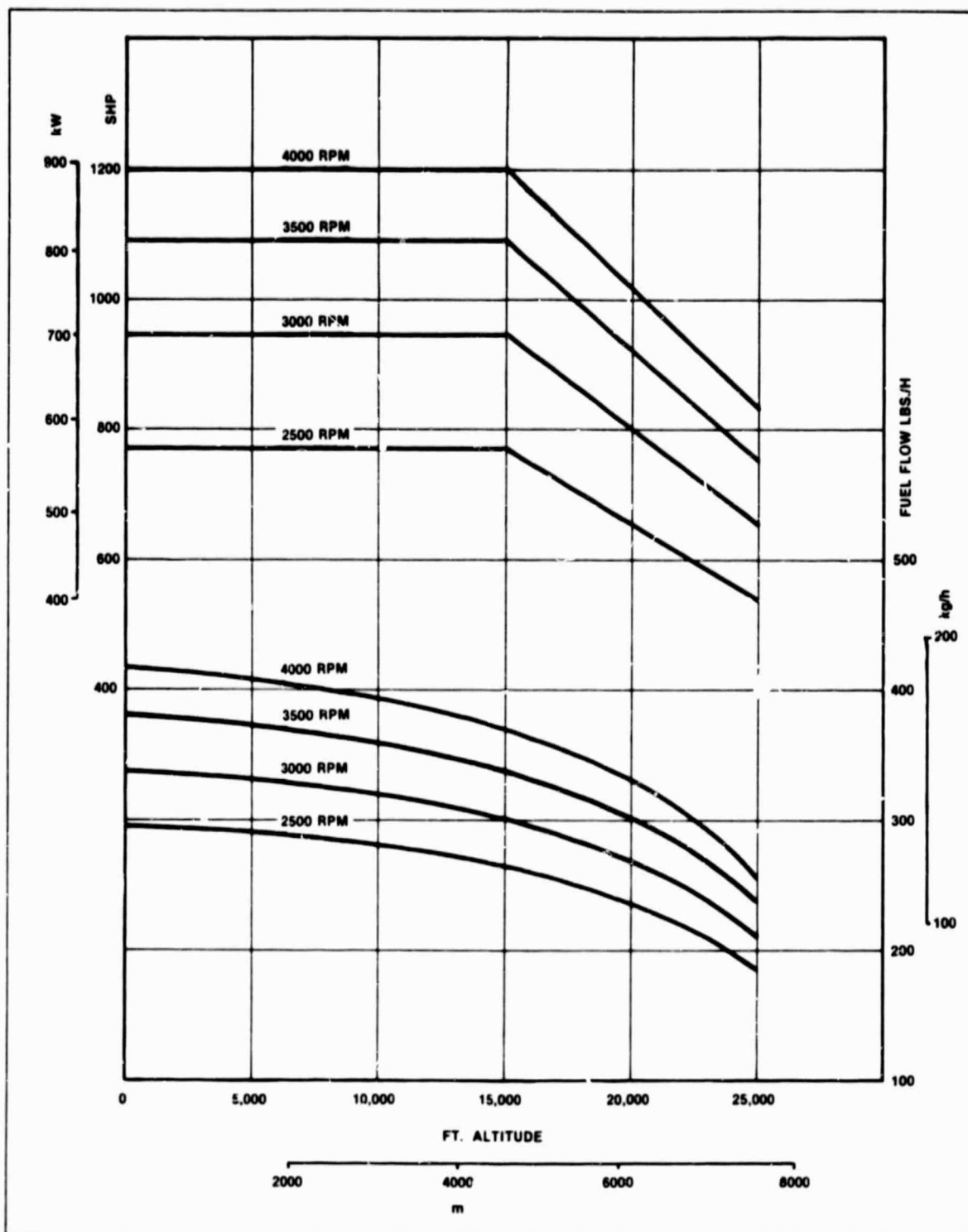


FIGURE 4-11 — 895 kW COMMUTER AIRCRAFT DIESEL MAXIMUM SHP AND FUEL FLOW

**TABLE XV**  
**895 kW Fuel Flow at 4572m (15000 ft.) at Max. SHP**

| RPM  | Prop<br>kW<br>HP | Cranksh.<br>kW<br>HP | Turbine |              | Engine<br>kW<br>HP | Piston<br>Engine BSFC<br>g/kWh<br>lb/HPh | Compounded<br>Fuel Flow<br>kg/h<br>lb/h | BSFC<br>g/kWh<br>lb/HPh |
|------|------------------|----------------------|---------|--------------|--------------------|--|---|-------------------------|
|      |                  |                      | % Total | Net kW<br>HP |                    |  |   |                         |
| 4000 | 895              | 937                  | 19.6    | 184          | 753                | 222                                      | 167                                     | 187                     |
|      | 1200             | 1257                 |         | 247          | 1010               | .365                                     | 369                                     | .308                    |
| 3500 | 812              | 854                  | 18.0    | 154          | 700                | 219                                      | 153                                     | 188                     |
|      | 1085             | 1145                 |         | 206          | 939                | .360                                     | 338                                     | .310                    |
| 3000 | 705              | 744                  | 16.0    | 119          | 625                | 219                                      | 137                                     | 194                     |
|      | 945              | 998                  |         | 160          | 838                | .360                                     | 302                                     | .320                    |
| 2500 | 575              | 614                  | 13.0    | 80           | 535                | 225                                      | 120                                     | 209                     |
|      | 771              | 824                  |         | 107          | 717                | .370                                     | 265                                     | .344                    |

**TABLE XVI**  
**895 kW Fuel Flow at 7620m (25000 ft.) at Max. SHP**

| RPM  | Prop<br>kW<br>HP | Cranksh.<br>kW<br>HP | Turbine |              | Engine<br>kW<br>HP | Piston<br>Engine BSFC<br>G/kWh<br>lb/HPh | Compounded<br>Fuel Flow<br>kg/h<br>lb/h | BSFC<br>g/kWh<br>lb/HPh |
|------|------------------|----------------------|---------|--------------|--------------------|--|---|-------------------------|
|      |                  |                      | % Total | Net kW<br>HP |                    |  |   |                         |
| 4000 | 620              | 660                  | 19.2    | 127          | 533                | 219                                      | 117                                     | 189                     |
|      | 832              | 885                  |         | 170          | 715                | .360                                     | 257                                     | .309                    |
| 3500 | 563              | 602                  | 17.5    | 105          | 497                | 216                                      | 107                                     | 190                     |
|      | 755              | 807                  |         | 141          | 666                | .355                                     | 236                                     | .313                    |
| 3000 | 488              | 526                  | 15.5    | 81           | 445                | 216                                      | 96                                      | 197                     |
|      | 655              | 706                  |         | 109          | 597                | .355                                     | 212                                     | .324                    |
| 2500 | 399              | 436                  | 12.5    | 54           | 382                | 222                                      | 85                                      | 213                     |
|      | 535              | 585                  |         | 73           | 512                | .365                                     | 187                                     | .350                    |

### 3. Fuel flow at idle RPM.

The estimated idle fuel flow is listed in the tabulation below. Uncertainties are the FMEP and the friction SFC.

|                |                        |
|----------------|------------------------|
| Idle Speed     | 1000 RPM               |
| FMEP           | 1.52 bar (22 psi)      |
| Friction Power | 19 kW (26 HP)          |
| Friction SFC   | 487 g/kWh (.80 lb/HPh) |
| Idle Fuel Flow | 9.5 kg/h (21 lb/h)     |

If 15 kW (20 HP) accessory power is included:

|              |                        |
|--------------|------------------------|
| Engine Power | 34 kW (46 HP)          |
| BSFC         | 456 g/kWh (.75 lb/HPh) |
| Fuel Flow    | 16 kg/h (35 lb/h)      |

#### 4. Power settings.

Following are full load and part load power settings.

##### A. Takeoff power at 32.5°C (90°F).

The previous calculations are based on 15.0°C (59°F) ambient air temperature. The temperature correction factor is 1% power reduction per 5.56°C (10°F).

|                                 |                  |
|---------------------------------|------------------|
| Temp corrected crankshaft power | 891 kW (1195 HP) |
| Accessory power + gear losses   | -24 kW (32 HP)   |
| Nominal prop power              | 867 kW (1163 HP) |

##### B. Maximum climb power @ ISA conditions:

- The power plant is flat rated at 895 kW (1200 SHP) to 4572m (15000 ft.).
- Above 4572m (15000 ft.) the climb power will decrease with altitude from 895 kW (1200 HP) to 620 kW (832 HP) at 7620m (25000 ft.) due to the specific design of the turbo machinery.

##### C. Partial power @ ISA conditions:

The Figures 4-7 through 4-9 show the fuel flows as a function of the nominal propeller power, engine RPM and altitude. The end points of the curves represent the 100% power setting.

### 4.5 Engine Physical Characteristics

A study was made of the engine weight, location of the center of gravity and the overall dimensions.

#### 4.5.1 ENGINE WEIGHT ANALYSIS

A weight analysis was conducted of two versions of the proposed engine:

1. A conventional version uses conventional materials.
2. An advanced version of equal performance uses advanced lightweight material technologies.

A detailed weight analysis is shown in Table XVII.

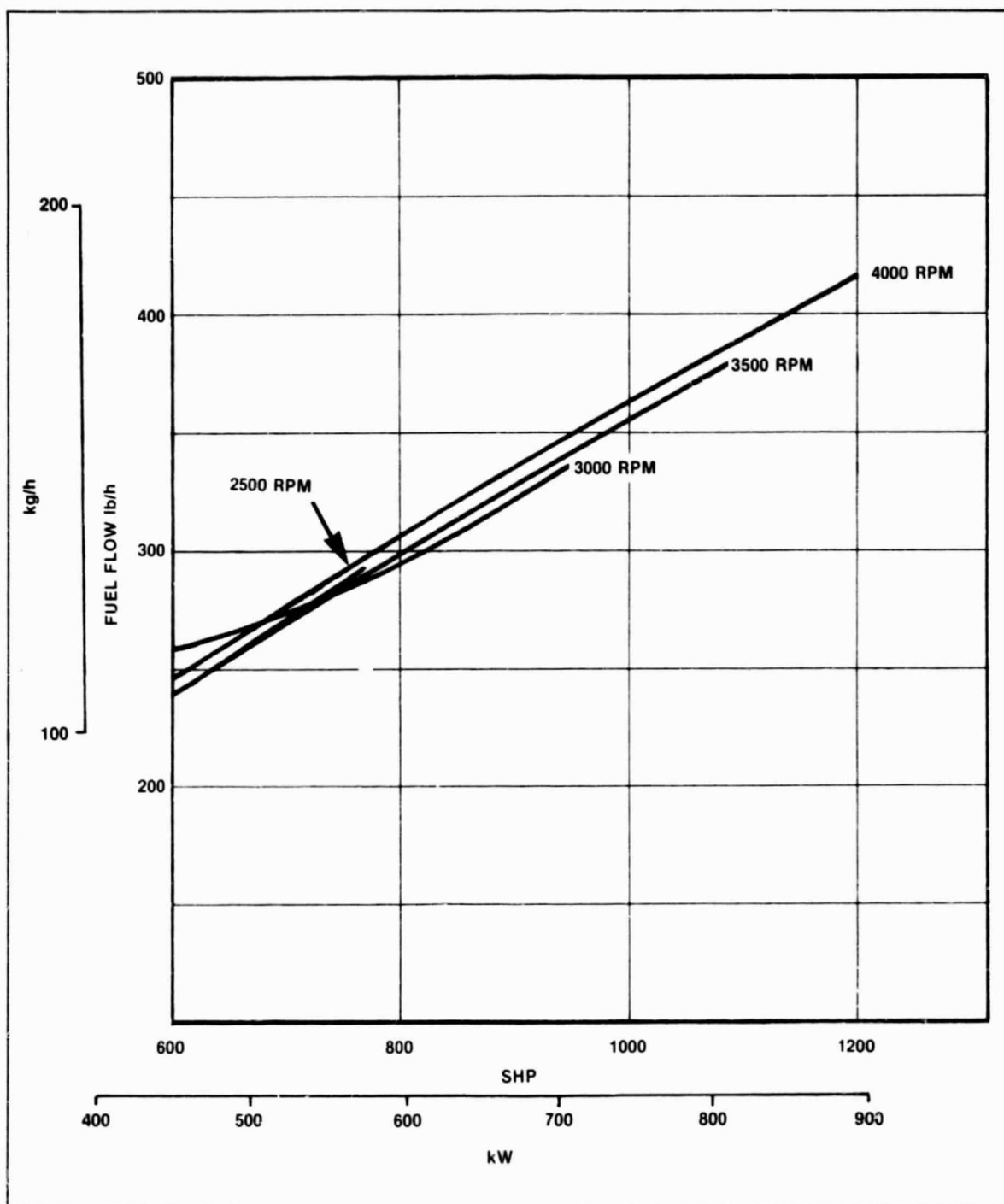


FIGURE 4-12 — 895 kW COMMUTER AIRCRAFT DIESEL PART LOAD FUEL CONSUMPTION AT SEA LEVEL

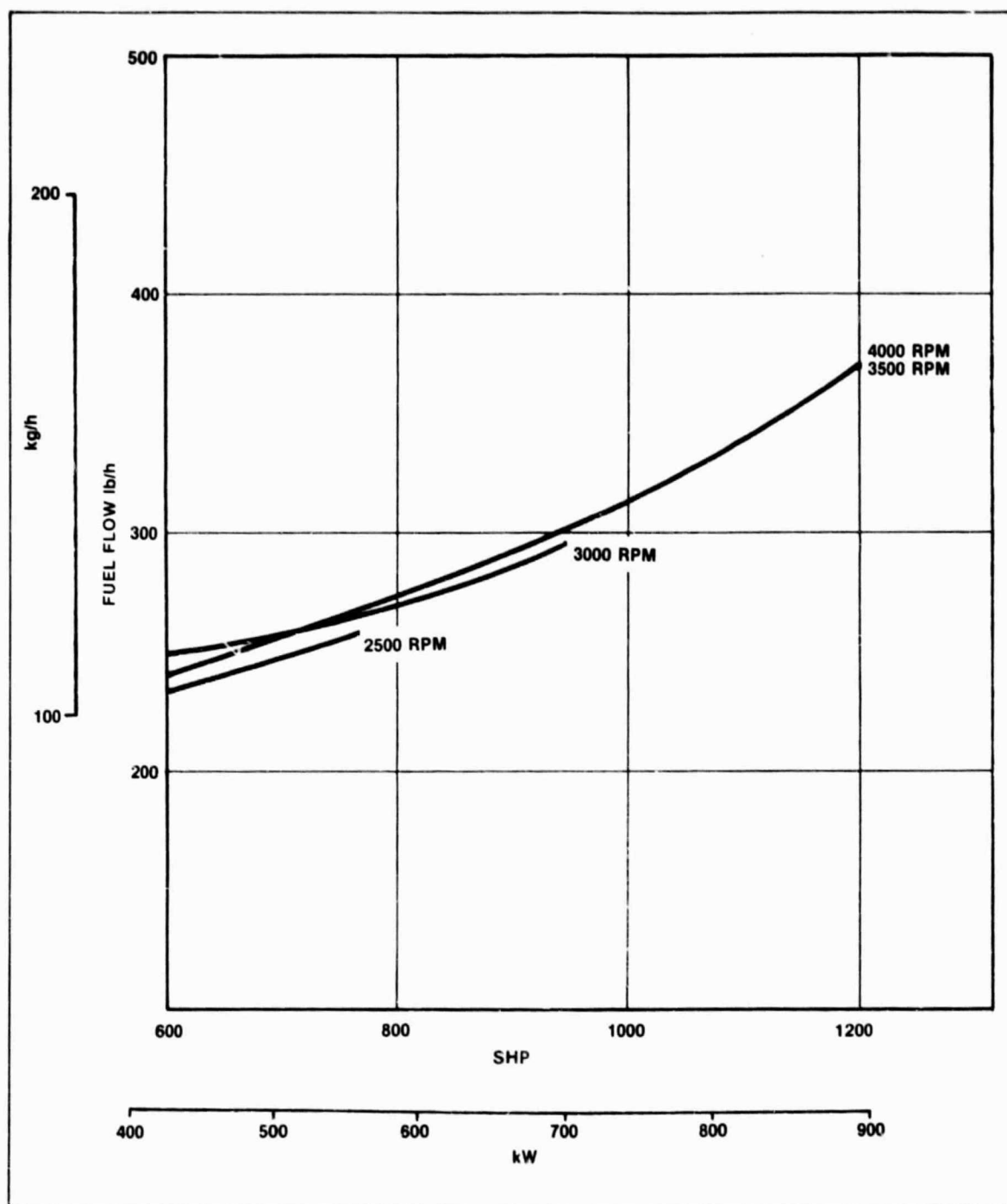


FIGURE 4-13 — 895 kW COMMUTER AIRCRAFT DIESEL PART LOAD FUEL CONSUMPTION AT 4572m ALTITUDE



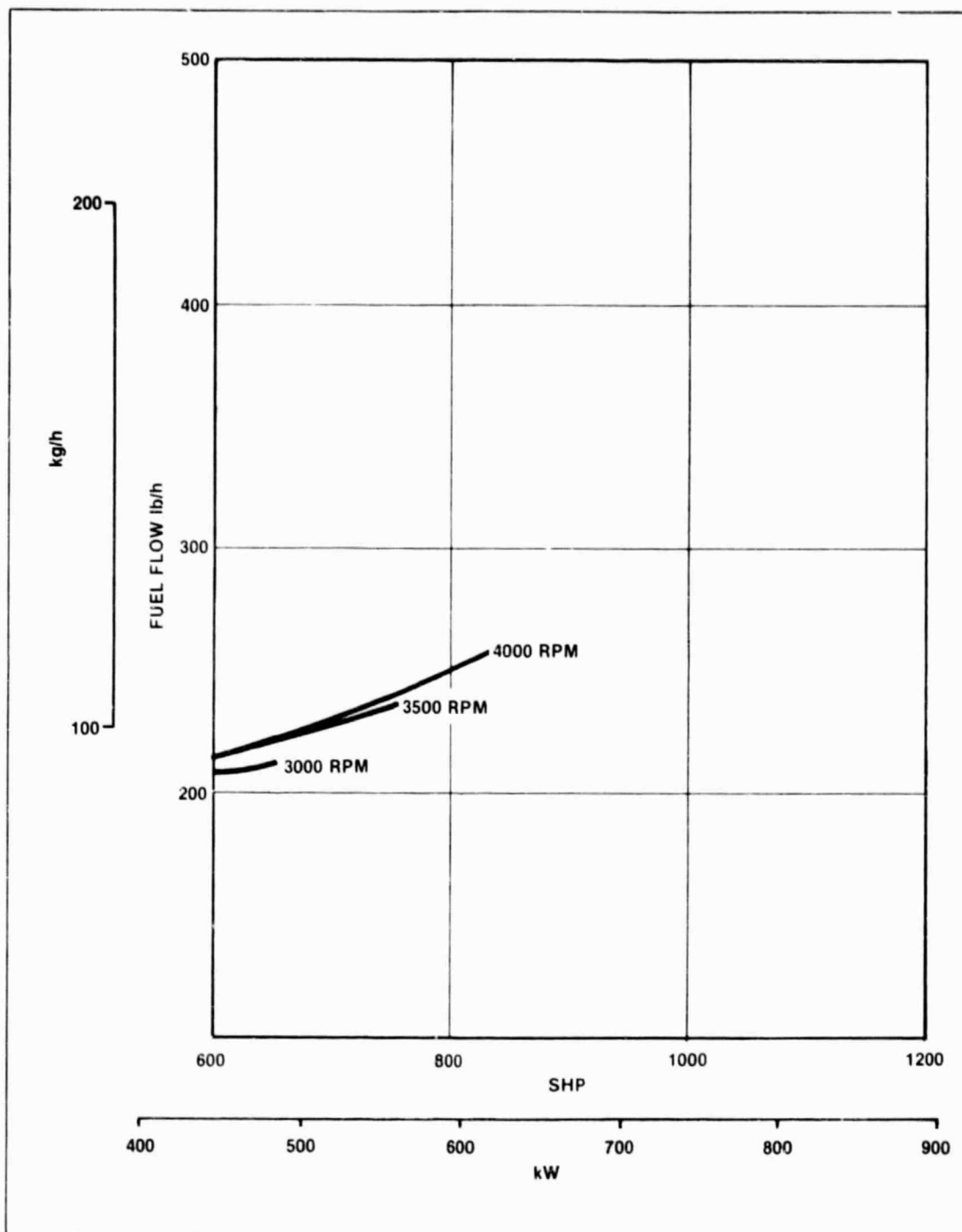


FIGURE 4-14 — 1200 SHP COMMUTER AIRCRAFT DIESEL PART LOAD FUEL CONSUMPTION AT 7620m ALTITUDE

**TABLE XVII**  
**895 kW (1200 HP) Weight Analysis**

| Component             | Weight   |      |              |      |
|-----------------------|----------|------|--------------|------|
|                       | Advanced |      | Conventional |      |
|                       | kg       | lb   | kg           | lb   |
| Prop Gear Housing     | 16       | 36   | 19           | 42   |
| Crankshaft            | 24       | 53   | 24           | 53   |
| Prop Drive Gear       | 7        | 16   | 8            | 18   |
| Pinions               | 15       | 32   | 16           | 36   |
| Sun Gear              | 3        | 6    | 3            | 6    |
| Cylinders             | 59       | 129  | 59           | 129  |
| Pistons               | 21       | 47   | 28           | 62   |
| Piston Pins           | 6        | 15   | 6            | 15   |
| Connecting Rods       | 14       | 31   | 23           | 51   |
| Crankcase             | 13       | 28   | 14           | 34   |
| Intake Manifolds      | 15       | 32   | 18           | 40   |
| Exhaust Manifolds     | 14       | 30   | 13           | 30   |
| Accessory Drive Gears | 3        | 7    | 3            | 8    |
| Injection System      | 28       | 62   | 28           | 62   |
| Governor              | 1        | 3    | 1            | 3    |
| Vacuum Pump           | 1        | 3    | 1            | 3    |
| Oil Pump              | 4        | 9    | 4            | 10   |
| Starter               | 22       | 48   | 22           | 48   |
| Generator             | 22       | 48   | 22           | 48   |
| Oil Cooler            | 9        | 20   | 9            | 20   |
| Compressor/Turbine    | 86       | 190  | 110          | 243  |
| Turbine Drive Gearing | 22       | 48   | 24           | 55   |
| Balance of Parts      | 40       | 87   | 45           | 99   |
| Engine Weight-Dry     | 445      | 980  | 500          | 1105 |
| Oil & Tank Weight     | 20       | 45   | 20           | 45   |
| Engine Weight-Wet     | 465      | 1025 | 520          | 1150 |

The specific weights, referenced to the 895 kW (1200 SHP) takeoff power are:

|                        | kg/kW | lb/HP |
|------------------------|-------|-------|
| Advanced Materials     | .520  | .854  |
| Conventional Materials | .581  | .958  |

#### 4.5.2 LOCATION OF THE ENGINE CENTER OF GRAVITY

The center of gravity was determined in two directions. It is assumed to be on the vertical axis of the engine.

**A. Horizontally.**

170mm (6.67") behind the centerline of the front row of cylinders.

**B. Vertically.**

80mm (3.34") below the crankshaft centerline.

### 4.5.3 ENGINE DIMENSIONS

The overall engine dimensions are:

|              |   |
|--------------|---|
| Length       | 1380mm ( 54.29 in.)                             |
| Width        | 840mm ( 33.04 in.)                              |
| Height       | 950mm ( 37.37 in.)                              |
| Volume       | 1098 dm <sup>3</sup> ( 38.79 ft. <sup>3</sup> ) |
| Frontal Area | 4394 cm <sup>2</sup> (681 in. <sup>2</sup> )    |

## 5.0 SCALING INFORMATION

The data generated in the Chapters 3 and 4 have been extrapolated to establish the physical characteristics and engine performance data over a power range from 670 kW (900 SHP) to 1865 kW (2500 SHP). All parameters are expressed as a function of the takeoff power at ISA conditions. Because of the specific designs in this study, the equations should not be used to scale data below 900 HP.

### 5.1 Engine Weight

The weight is defined as the wet weight of a complete power plant and includes all accessories.

#### 1. Advanced Material Engine.

- Weight =  $10.09 (\text{kW})^{.564}$  kg where kW = takeoff power in kW

$$\text{Specific weight} = 10.09 (\text{SHP})^{-.436} \text{ kg/kW}$$

- Weight =  $18.81 (\text{SHP})^{.564}$  lb where SHP = takeoff power in HP

$$\text{Specific weight} = 18.81 (\text{SHP})^{-.436} \text{ lb/HP}$$

#### 2. Conventional Material Engine.

- Weight =  $8.22 (\text{kW})^{.610}$  kg

$$\text{Specific weight} = 8.22 (\text{kW})^{-.390} \text{ kg/kW}$$

- Weight =  $15.17 (\text{SHP})^{.610}$  lb

$$\text{Specific weight} = 15.17 (\text{SHP})^{-.390} \text{ lb/HP}$$

### 5.2 Size vs. SHP Relationship

No size difference is assumed between advanced and conventional material engines. The difference in cylinder configuration between 6 cylinder and 8 cylinder engines requires a different scaling approach for each arrangement.

- The following tabulation of cylinder configurations was used to determine the dimensional trends over the considered power range:

| SHP  |      | No. of<br>Cylinders | RPM  | Displ. |                  | Bore x Stroke |             |
|------|------|---------------------|------|--------|------------------|---------------|-------------|
| kW   | HP   |                     |      | l      | in. <sup>3</sup> | mm            | inch        |
| 670  | 900  | 6                   | 4400 | 5.08   | 310              | 99.4 x 109.3  | 3.91 x 4.30 |
| 895  | 1200 | 6                   | 4000 | 7.59   | 463              | 114.0 x 124.0 | 4.49 x 4.92 |
| 1119 | 1500 | 6                   | 4000 | 9.54   | 582              | 122.5 x 134.8 | 4.82 x 5.31 |
| 1119 | 1500 | 8                   | 4000 | 9.54   | 582              | 111.3 x 122.5 | 4.38 x 4.82 |
| 1491 | 2000 | 8                   | 4000 | 12.67  | 773              | 122.0 x 135.0 | 4.80 x 5.34 |
| 1865 | 2500 | 8                   | 3600 | 17.65  | 1077             | 136.7 x 150.3 | 5.38 x 5.92 |

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2. Width and height of 6 cylinder engines:

| SHP<br>kW | Width |      | Height |      |
|-----------|-------|------|--------|------|
|           | mm    | inch | mm     | inch |
| 670       | 735   | 28.9 | 830    | 32.7 |
| 895       | 839   | 33.0 | 949    | 37.4 |
| 1119      | 905   | 35.6 | 1023   | 40.3 |

3. Width and height of 8 cylinder engines:

| SHP<br>kW | Width |      | Height |      |
|-----------|-------|------|--------|------|
|           | mm    | inch | mm     | inch |
| 1119      | 679   | 26.7 | 813    | 32.0 |
| 1491      | 751   | 29.6 | 900    | 35.4 |
| 1864      | 833   | 32.8 | 998    | 39.3 |

4. Engine length of 6 cylinder and 8 cylinder engines:

$$L = 498 (\text{kW})^{.15} \text{ mm}$$

$$L = 18.75 (\text{SHP})^{.15} \text{ inch.}$$

### 5.3 Fuel Consumption vs. SHP.

Trends for fuel flow and specific fuel consumption were established for takeoff and maximum cruise power conditions at 4572m (15000 ft.) and 7620m (25000 ft.) altitude.

1. Takeoff power:

- Fuel flow =  $.323 (\text{kW})^{.938} \text{ kg/h}$

$$\text{SFC} = .323 (\text{kW})^{-.062} \text{ kg/kWh}$$

- Fuel flow =  $.541 (\text{SHP})^{.938} \text{ lb/h}$

$$\text{SFC} = .541 (\text{SHP})^{-.062} \text{ lb/HPh}$$

2. Maximum cruise power at 4572m (15000 ft.) altitude:

- Fuel flow =  $.272 (\text{kW})^{.945} \text{ kg/h}$

$$\text{SFC} = .272 (\text{kW})^{-.055} \text{ kg/kWh}$$

- Fuel flow =  $.454 (\text{SHP})^{.945} \text{ lb/h}$

$$\text{SFC} = .454 (\text{SHP})^{-.055} \text{ lb/HPh}$$

3. Maximum cruise power at 7620m (25000 ft.) altitude:

- Fuel flow =  $.312 (\text{kW})^{.921} \text{ kg/h}$

$$\text{SFC} = .312 (\text{kW})^{-.079} \text{ kg/kWh}$$

- Fuel flow =  $.525 (\text{SHP})^{.921} \text{ lb/h}$

$$\text{SFC} = .525 (\text{SHP})^{-.079} \text{ lb/HPh}$$

## **6.0 CONCLUSIONS**

1. The advanced technology diesel engine with its very low SFC and light weight appears to be an attractive engine candidate for aircraft applications.
2. Diesel engines can have a flat rating potential for full power cruise at higher altitudes which may be advantageous for some applications.
3. Detailed mission studies are required to determine the competitive nature of the diesel engine (relative to other power plants) based on aircraft applications and trip lengths.
4. Additional and more detailed studies are required to obtain engine and maintenance costs.

## 7.0 LIST OF REFERENCES

1. "150 and 300 kW Lightweight Diesel Aircraft Engine Design Study," NASA Report CR 3260
2. "186 Net kW Lightweight Diesel Aircraft Engine," NASA Report CR 3261
3. "Napier Nomad Aircraft Diesel Engine," H. Sammons and E. Chatterton, SAE Transactions Volume 63, 1955

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